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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

Measuring Large Doses

A Nucleonics special report on high-level dosimetry... page 57

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BY

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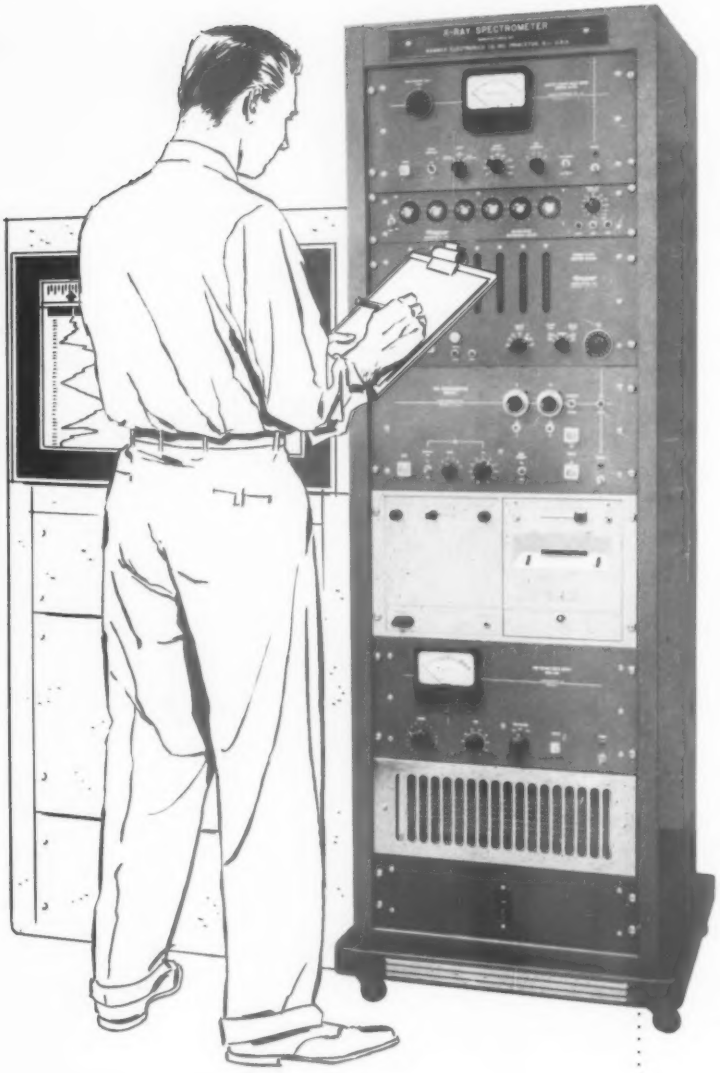

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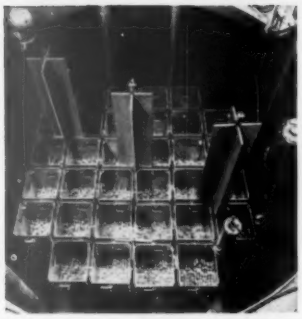

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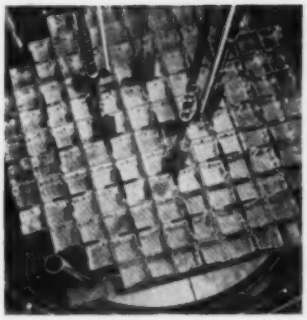

Critical experiment core for the thorium converter reactor designed and being built by B&W for the Consolidated Edison Company of New York (Indian Point).

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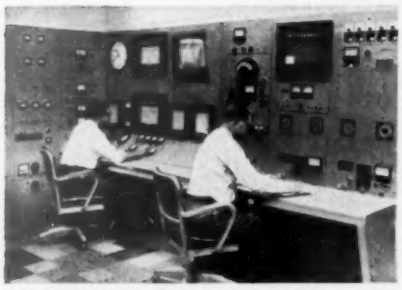
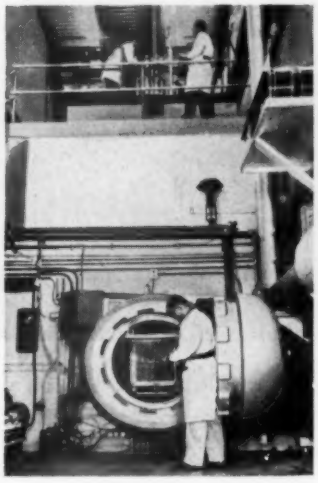
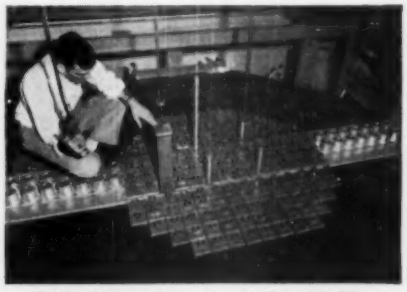


B&W-designed control panel for one of its critical experiment bays.





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About NUCLEONICS

Gaging the Dose

Competent observers see a great future for radiation in industrial processing (NU, June '59, p. 114). The heavy investment by both government and industry in such applications as food sterilization, rubber vulcanization and crosslinking of plastics, bears this out.

Both for the large-scale applications of radiation that will someday be with us and for the research studies that must necessarily precede them, it is important to be able to measure radiation dose accurately and conveniently. The same richness of phenomenon in the interaction of radiation with matter that has opened so many intriguing paths for the application of radiation has also resulted in a plentitude of dosimetric methods. In the NUCLEONICS report on high-level dosimetry that is presented in this issue, the full range of these dosimetry systems is tabulated and discussed. From the classic ferrous-ferric dosimetry of Fricke to the promising luminescence degradation techniques that Attix discusses, from systems based on counting bacteria to systems counting electrons—all are included here.

Associate Editor Hoby Ellis is the man behind this comprehensive report, which was conceived more than a year ago when he and several others interested in radiation dosimetry gathered around a dinner table to discuss what the field needed.

We feel no need to encourage the radiation specialists among you to read this report—it is required reading for them. But for those of you whose first love is nuclear fission and power reactors we would urge at least perusal of this report. NUCLEONICS is founded on the thesis of a community of nuclear interests and we believe this wholeness will be borne out by the unexpected benefits that will flow from improved understanding of how radiation can be measured.

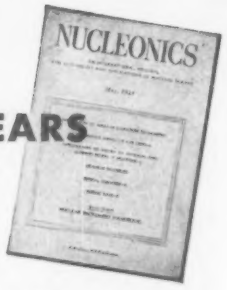
A Message in the Noise

In his "Murders in the Rue Morgue" Edgar Allen Poe has his hero decide that the murderer is not a man but an ape because his babble proved unintelligible to listeners of several different native tongues. For the skilled investigator there is a message even where others would hear only noise.

Extraction of messages from noisy backgrounds has been a subject of intense interest to information theorists—men like Norbert Wiener and Claude Shannon—for at least 15 years. Now the techniques are coming into their own in the nuclear field—witness the excellent discussion of stability measurements in EBWR on p. 102 of this issue. The work is based on little more than listening to the neutrons hum, but from it comes real insight into how EBWR works.

—*The Editors*

10 YEARS AGO



Jordan and Bell. Those of you who first started counting scintillations during the past five years probably think of scintillation counters as an off-the-shelf, prepackaged item. It was not always so. In 1949 the postwar revolution in scintillation counting that stemmed from Kallmann's work on naphthalene was in full vigor. A conference devoted entirely to scintillation counters was held in Oak Ridge in June, 1949; NUCLEONICS' report on that conference, written by two pioneers in the field, is worthwhile reading for those who like a bit of insight with their prepackaging.—W. H. Jordan, P. R. Bell, NUCLEONICS, Oct. '49, p. 30.

Momentous nuclei. A property of the atomic nucleus that is generally ignored as a concern of the nuclear industry is its magnetic moment. This in spite of the fact that the sharp nuclear magnetic resonance lines that can be observed when the nucleus is placed in an external magnetic field have proved to be a useful analytical tool. Perhaps we should not be ignoring any phenomenon that provides a "handle" on the nucleus. An introductory article in the October, 1949 issue of NUCLEONICS can start you off on the subject.—F. Bitter, NUCLEONICS, Oct. '49, p. 16.

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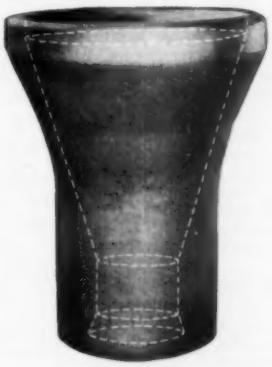
Height: 4"
Outside Diameter of Small End: 5.25"
Weight: 42.25 lbs.

Forging of Turbine Rotor Stub Shaft for Nuclear Jet Engine
Material: A-286 Steel
Outside Diameter of Cone End: 33.687"
Outside Diameter of Shaft: 10.375"
Height: 44.875"
Weight: 1150 lbs.

Forging of a J-93 Front Turbine Shaft for Aircraft Gas Turbine Engine
Material: Waspalloy
Diameter of Conical End: 23.38"
Diameter of Hub End: 6.50"
Length: 27.68"
Weight: 430 lbs.



Forging of a Liner — Exit Cone Missile
Material: Unalloyed Arc Cast Molybdenum
Diameter of Large Conical End: 10.50"
Height: 12.89"
Diameter of Small Conical End: 6.75"
Weight: 104.5 lbs.

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NUCLEAR REACTIONS

Stainless vs. Zircaloy

DEAR SIR:

In the article "Which for Minimum Fuel Cost—Zircaloy or Stainless Clad?" in the July 1959 issue of NUCLEONICS (p. 64), we would like to point out that the conclusions reached on the economic advantage of zircaloy over stainless steel cladding are not as clearcut as may be inferred from the article. Re-evaluation of the cost assumptions will not only change the absolute values of the fuel costs, but also the relative economy of the two materials. As an example of this, leaving the uranium rental at 4% and using the values given by the authors for the other costs will move the "breakeven point" from 5,000 to 12,000 Mwd/ton in the curve of possible future U. S. costs. See Fig. 1.

Beecher and Benedict have used Euratom prices for fabrication costs of $100 and $140 per kg of uranium contained for stainless and zircaloy respectively. However, the Euratom quotes increase to $128 and $176 per kg of uranium contained at a burnup of 12,000 Mwd/ton. These last figures are a much more realistic assumption to make at the present time. On this basis, and using the present uranium rental of 4% (a figure likely to remain constant), the "breakeven point" is advanced to approximately 14,000 Mwd/ton for plutonium prices in the range from $12 to 30/gram. This results in an appreciable difference from the values given in the article. See Fig. 2.

Should future technical developments allow the use of non-free-standing stainless-steel cladding, the enrichments required for stainless steel will be appreciably reduced, resulting in a considerable savings in fuel cost. On this basis it can be shown that stainless steel is more economical even beyond 25,000 Mwd/ton; see Fig. 3.

The inferences of the term "breakeven point" are also misleading, causing the reader to neglect other considerations based on physical properties. At the so-called "breakeven point," stainless steel would still be the preferred material because of its safety aspects and actual operational history. Stainless steel has a more gradual reduction in strength with increasing temperature than does zircaloy, an important characteristic during high temperature transient

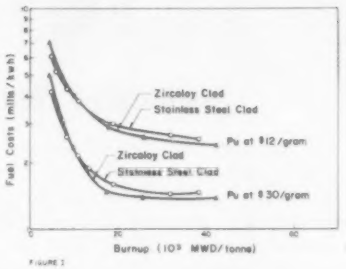

FIGURE 1

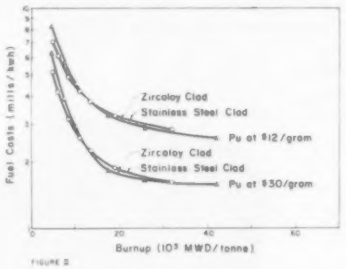

FIGURE 2

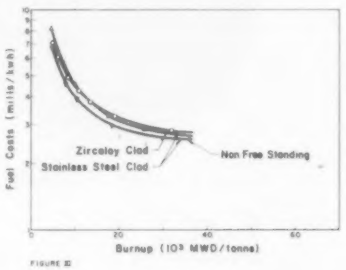

FIGURE 3

conditions in the reactor. Then too, it is not plagued with the hydriding problem that renders zircaloy susceptible to embrittlement after long lifetime in the reactor. Furthermore, the potential threat of the zirconium-water reaction with its consequent energy release may necessitate an increase in vapor container requirements.

The state of the art is such that a decision can only be made for each particular reactor application and at the time the reactor is to be used. The differences between the various curves (Figs. 1 and 2) are so small that the breakeven point can shift significantly with a minor variation in parametric conditions. In any event, we feel that with such small differences stainless steel is generally the preferred choice because there are fewer technical uncertainties in its manufacturing and subsequent operation.

—W. J. DOLLARD and
R. VON HOLLEN
Application Engineering Atomic Power Department—Forest Hills
Westinghouse Electric Corporation
Pittsburgh, Pa.

To D or Not to D

Bear Sir:

I reab with interest the tadle entitleb "Nucleonics Statistics of the Month" on p. 28 of the August 1959 issue.

Somedoby pulleb a dig doner!!!

—I. DRUSSEL-SMITH
Millwoob, N. Y.

Bear Sir:

We noteb your August issue and founb it most interesting. The section "Nucleonics Statistics of the Month" was belightful. Bib you set the type for this section immebiately after the ANS cocktail party or was it probuceb dy a cross-eyeb typesetter that bib not care if a "b" was a "d" or couldn't tell the bifference?

—EDWIN E. STOKELY
Oak Ribge, Tennessee

EBITORS NOTE:

Inbeeb 'tis sab, anb we are dlue;
'Twixt ebiting anb bummy glue,
Somehow we've mabe a dab doodoo—
Mayhap this dalmy danb now botes!

While we pudlish in the heat,
'Tis goob we were a dit biscreet
Anb bibn't this mistake repeat
As Bugway or "Inbustry Notes."

Dosimetry Comments

Dear Sir:

I read with great interest your article " . . . Pocket dosimeters? Film badges? . . . or both?" (NU, May '59, p. 116). As I am in charge of a personnel monitoring program, I also gave much thought to this matter and should like to make the following comments:

1. An important feature of the film badge method, not mentioned in this symposium, is its great flexibility. Ranges can be altered by using other films; new types of film and modified development techniques can be introduced. Even if the badges are to be replaced by other ones, the cost will be low. Thus adaptation to new methods does not meet with much objection, whereas pocket dosimeters cannot be modified and replacement is expensive.

2. The discussion did not involve *indirect-reading pocket chambers.* These are much cheaper and more rugged than the direct-reading instruments with their built-in electroscope. Moreover, like films, they are evaluated by an objective third party. Yet, contrary to film dosimetry, the results can be obtained with a minimum of

(*Continued on page 117*)

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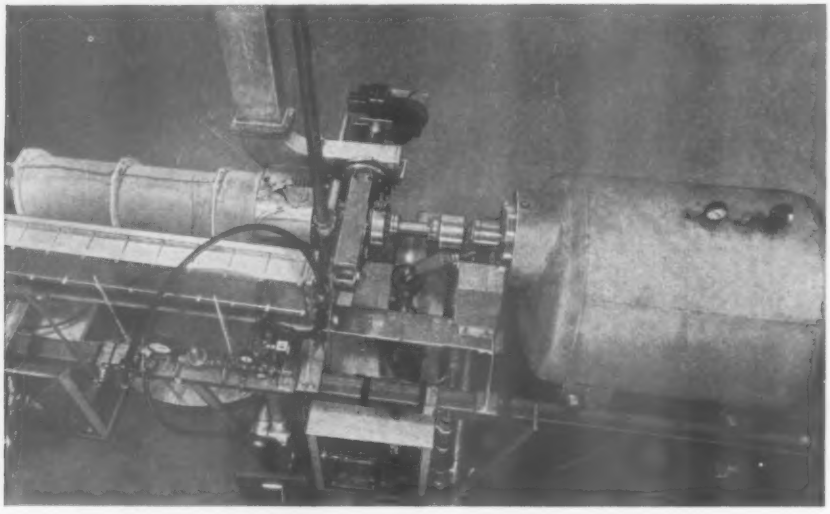

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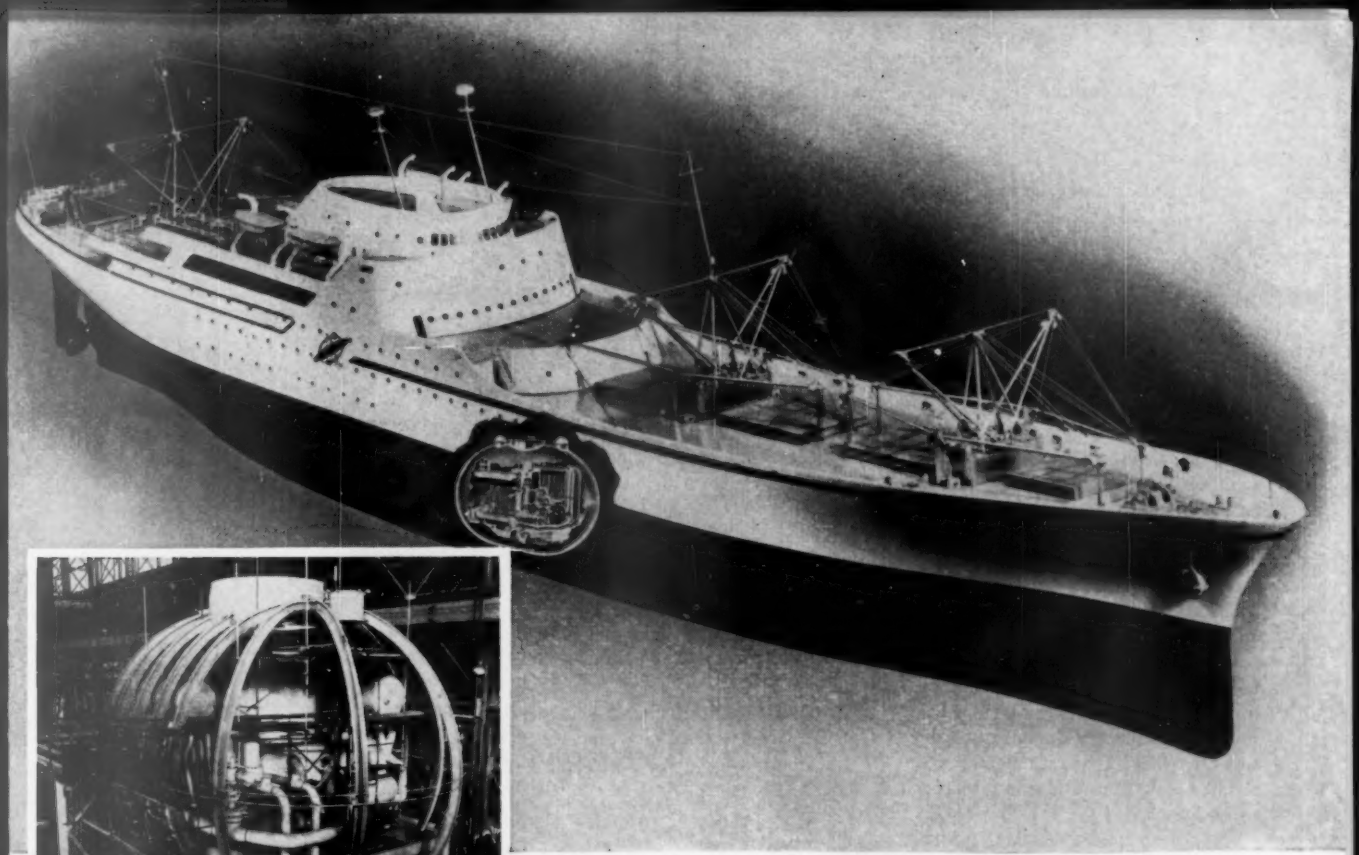

N. S. "Savannah," the first nuclear powered passenger-cargo vessel, carries Asarco shielding lead aboard as protection against radiation. (Photos through the courtesy of the builder, New York Shipbuilding Corporation—Camden, N. J.)

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Promising Rookie

a report by LINDSAY

Brought out of obscurity several years ago because of its exceptional promise, newcomer thorium is slated to achieve importance as a fertile material along with the veteran, uranium. Actually, some of its properties have led several sage talent scouts to predict that thorium will outshine uranium as a fertile material long before the latter has passed its prime.

Such predictions are based not so much on the properties of thorium, as on those of the fuel produced as a result of its irradiation. The fact that U^{233} has a neutron yield considerably higher than that of either U^{235} or Pu^{239} makes possible the operation of reactors using thorium for the fertile material at conversion ratios close to, if not exceeding, 1.0.

This permits substantial neutron economies due to the need for less reactivity control. It decreases the need for so many control rods and housings; and, of course, it decreases fuel burn-up costs measurably.

CAN GO THE DISTANCE

Assuming that fuel elements capable of withstanding the radiation damage can be produced, thorium also opens the way for consideration of fuel elements which could operate for 20,000-30,000 MWD/T. Even longer reactivity lifetimes could be anticipated if conversion ratios approximating 1.0 could actually be achieved.

As with all rookies, thorium has some unanticipated problems associated with its use. U^{232}, a by-product of thorium irradiation, decays, through Th^{228}, to a series of daughters which results in both the fuel and fertile material being radioactive. When compared with the use of clean, enriched uranium, this appears to be a serious disadvantage. Yet, when compared with the prospect of recycling the Pu and re-enriching the uranium which would come from uranium plants, the problems of dealing with the thorium cycle appear to be little if any more difficult.

Some fuel managers have been clever in planning fuel cycles using natural and slightly enriched uranium and if these prove to be real winners it would make sense to go along with them. Actually, some studies show that almost competitive nuclear power can be achieved by use of natural and very slightly enriched uranium, based on relatively short fuel lifetimes and considerable fuel juggling . . . like playing games with three pitchers, each of whom pitches three innings.

But is all this really necessary? The problems associated with the use of thorium are finite. The list of advantages and the promise are impressive. A little work and a lot of development could prove out thorium as the optimum fertile material for most reactors. Admittedly, considerable effort will be required to develop this youngster fully, but . . . *this is no time to send our bonus baby back to the minors.*

Actually, of course, thorium is no "rookie." We at Lindsay have been working with thorium compounds for nearly fifty years for a variety of industrial applications. We have ample production to meet any anticipated requirements and can supply to qualified people a considerable amount of data on thorium as a nuclear fuel.

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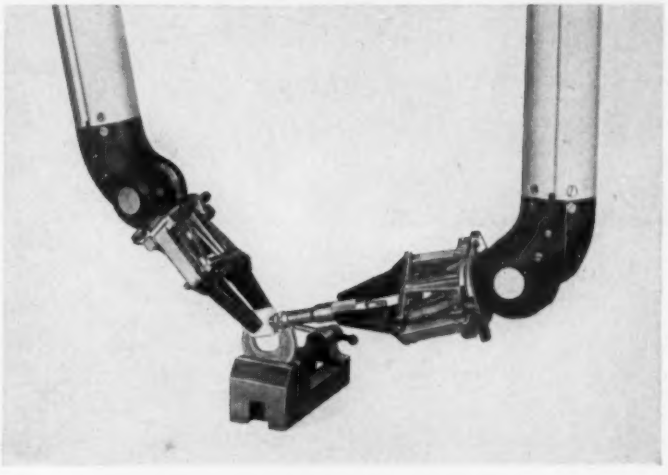

Central Research Manipulators from basic Argonne National Laboratory design

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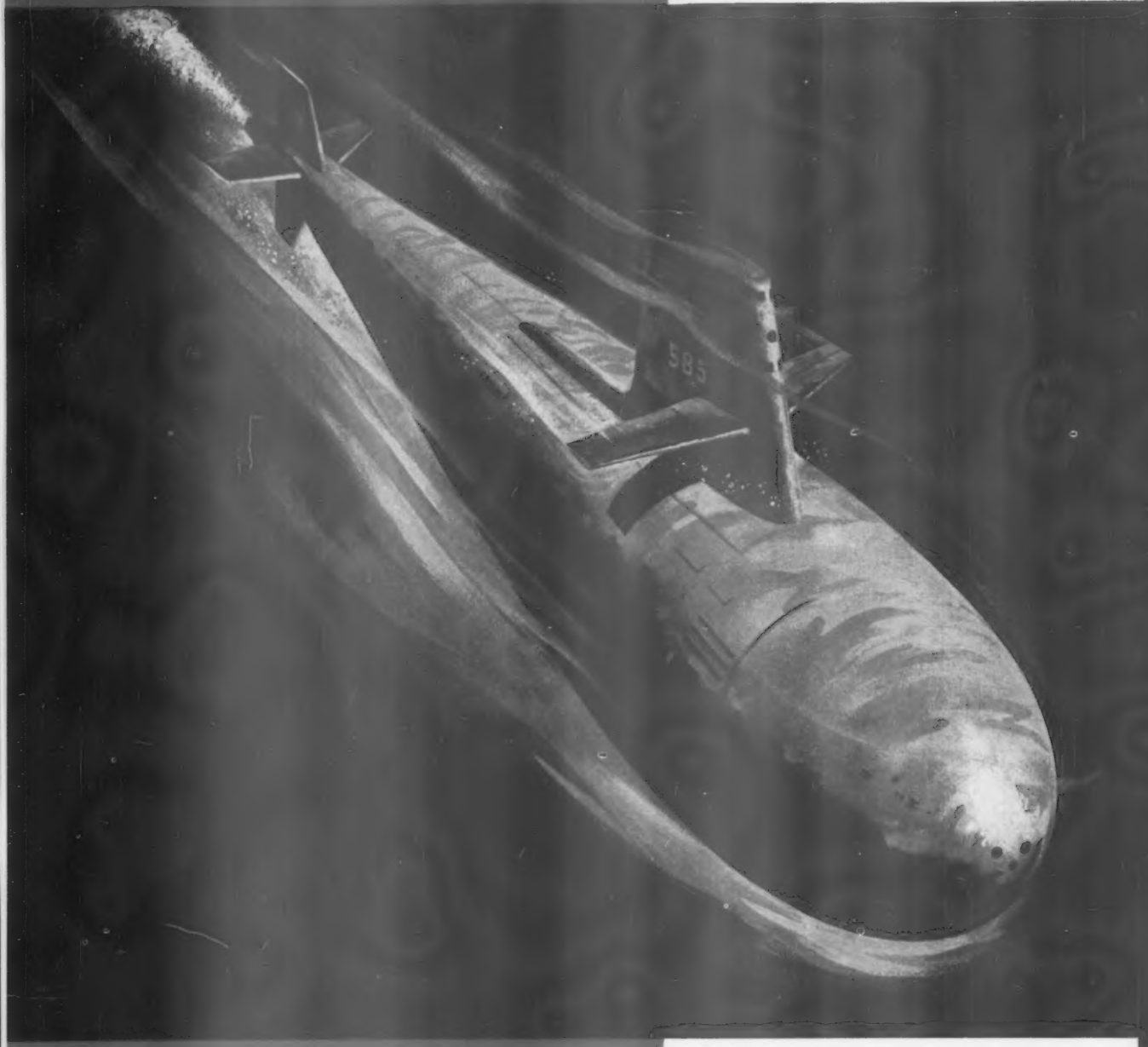

NEW LOOK IN NUCLEAR SUBS . . . The Navy's new submarine Skipjack, built by General Dynamics Corporation's Electric Boat Division in Groton, Connecticut, features a revolutionary blimp-shaped hull and diving planes on the sail (formerly known as the conning tower). Although her speed is classified, Skipjack is the fastest of the A-Subs.

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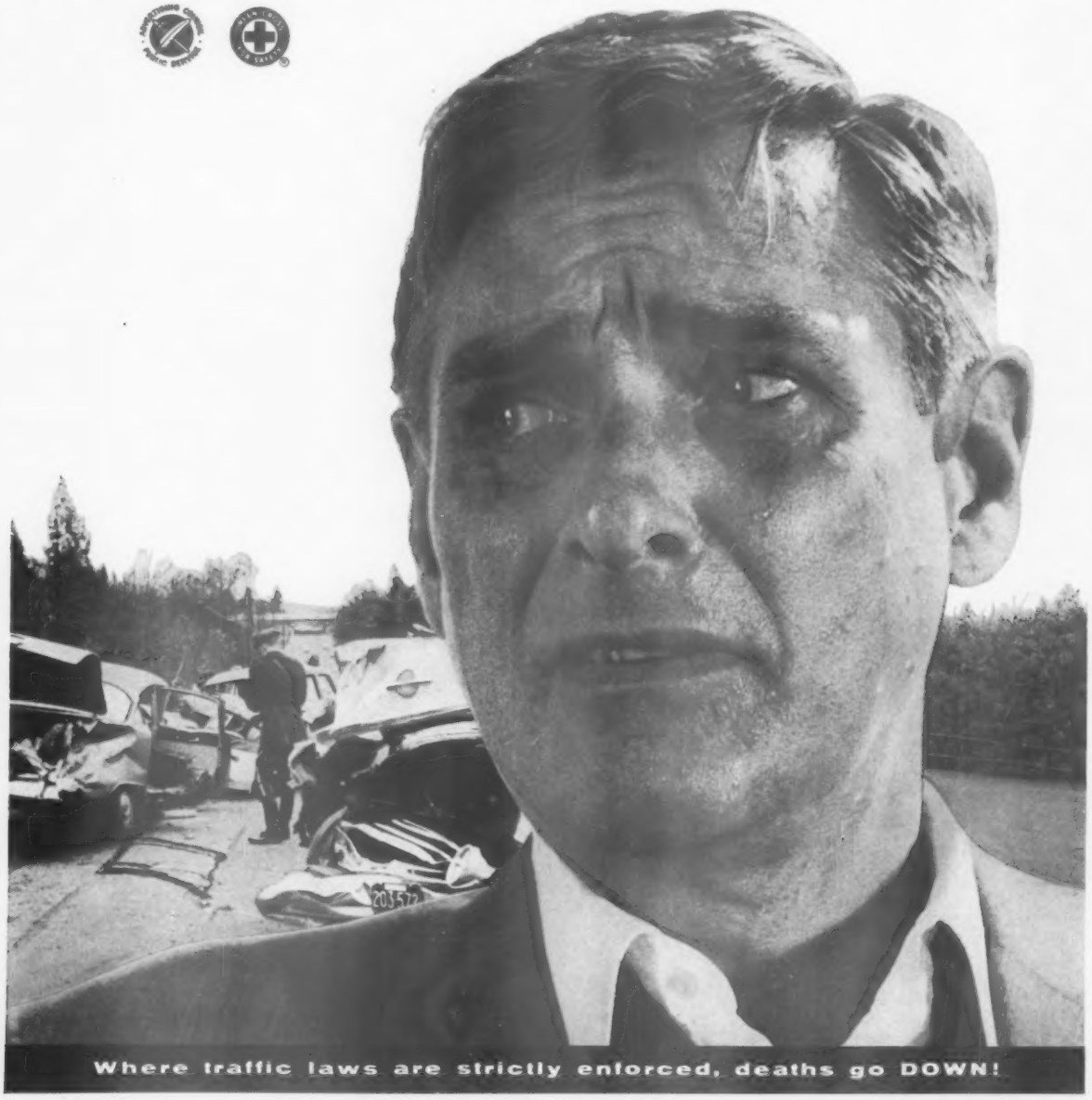

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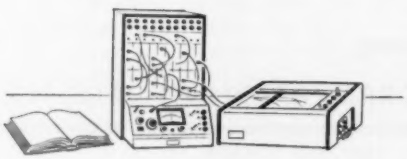

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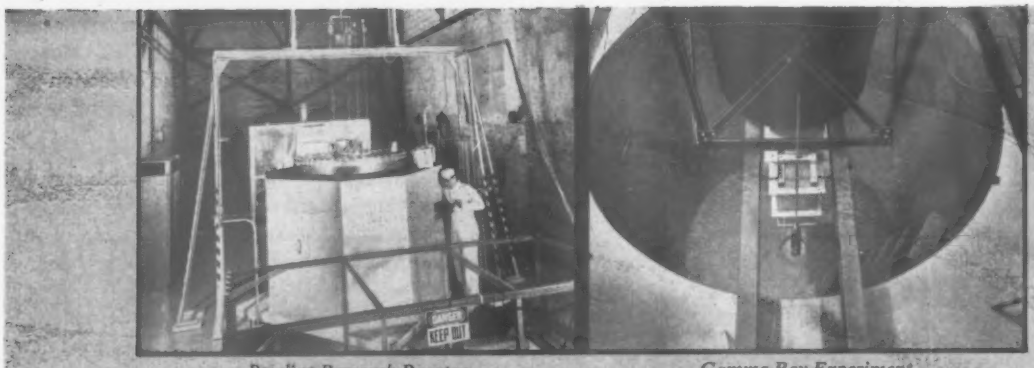

Pawling Research Reactor *Gamma Ray Experiment*

a complete reactor company at work

Control Room, Pawling Research Reactor

A reactor company's ability to gain the best solution with a given set of design parameters is proportional to the quality of its experimental physicists. This is why NDA maintains an experimental physics group that has gained a wide reputation for quality and productivity.

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NDA's experimental physics group conducts complete reactor core and shielding physics programs. It also addresses itself to specific problems such as exponential and single cell experiments, reactivity value studies and related projects to which the experimental physicist brings unique insights and skills.

Working for itself and others, NDA participates in reactor development on a broad front. As a result, it offers unusual opportunities for experimental physicists and other reactor scientists and engineers to grow with the company and the industry. Write for employment information.

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ROUNDUP of Key Developments in Nucleonics

Westinghouse Offers Guaranteed-Price A-Power

Westinghouse hit the hard-sell trail last month with a bold offer to utilities to build nuclear power plants at guaranteed cost.

The pioneering firm laid its reputation on the line by offering to "guarantee the manufacturer's controllable costs: plant capital cost, plant capability, and fuel burnup. Having these guaranteed, the cost of energy to the utility is directly a function of: plant load factor, individual annual charges, and operation and maintenance costs—all of which the utility can control." This, observers felt, was about the closest that nuclear power had yet been brought to treatment as conventional power.

Westinghouse, which has long been expressing the view that pressurized-water and boiling-water reactors will eventually merge into a single type having the best features of both, has now abandoned the terms "pressurized" and "boiling" and is offering reactors of both kinds, calling them "closed-cycle" and "direct-cycle" respectively.

The three reactors that Westinghouse salesmen are packing in their sample cases are:

1. The Combination Plant, using both nuclear and fossil fuel, was designed around a modern, 225 Mw(e) catalog-item turbine using steam at 1,800 psi, 1,000° F and 1,000° F reheat. A direct-cycle boiling reactor produces 2,115-psi dry saturated steam; a steam separating drum passes steam on to the superheater and returns water (and turbine condensate) to the core, which contains 26½ tons of 2%-enriched uranium-oxide pellets. The superheater can be fired with coal, oil or gas, and contributes 220 Mw(th) against the reactor's 300 Mw(th) to the plant's 225 Mw(e) net power output.

Power cost is estimated at 7.3 mills/kwh: 3.4 mills capital investment, 2.7 mills fuel (based on 30¢/million Btu oil for superheater), 0.5 mills land, interest, other fixed charges, and 0.7 mills operation and maintenance. Westinghouse will build this plant, starting today for completion in four years, for $4.5-million research-development costs and $45-million capital costs.

2. The Integral Boiling and Superheat Reactor (IBSHR) is a long-range project—a 20-Mw(e) pilot plant is proposed for now, leading to a 200-Mw(e) scale-up to operate in 1975. This is a graphite-moderated pressure-tube reactor with a central boiling and peripheral superheating region. (The arrangement is opposite from that in the water-moderated Northern States integral superheating reactor now under construction). The small pilot plant would deliver 850 psi, 900° F steam.

Westinghouse will built the pilot plant for about $11.3-million research-development money, about $17-million capital cost. This one is not covered by the guarantee, but it does promise the most economy in the more distant future, the company says.

3. The 330-Mw Closed-Cycle Plant, which is clearly Westinghouse's favorite, is a five-loop scale-up of Yankee based, the firm explains, on the facts that there is economy in large reactors and that the closed-cycle plant is the most proved type to date. (It's called closed-cycle instead of pressurized-water because there is nucleate boiling in the core, but there is a pressurizer in the primary loops.) It profits from improved vessel-fabricating technology with a 300-ton reactor vessel 41 ft high, 12 ft i.d., of 10-in. thick carbon steel clad with stainless.

Uranium oxide pellet fuel in stainless-steel or zircaloy tubes is arranged in three zones: 2.1% enriched in the center, 2.6% in a surrounding ring, and 2.9% in the peripheral zone. Loading is in three cycles, after each of which the central zone elements are removed, the two outer, partially-burned zones moved one step inward, and fresh 2.9% enriched elements added in the outer ring. This is said to provide uniform heat rate, fewer control rods, less expensive fuel, and more kilowatts per fuel load.

The five steam generators supply 4½-million lb/hr steam to the turbine at 650 psi, 495° F, dry and saturated.

Power cost is put at 7.3 mills/kwh: 3.3 mills capital cost, 3.0 mills fuel, 0.5 mills fixed charges, 0.5 mills operation and maintenance. Westinghouse will build it for $4.4-million research-development cost, $68-million plant cost ($206/kw installed).

Two teams of Westinghouse salesmen will present these three plants to 100 U. S. utilities in the next three months, then will visit Europe and Japan.

Santa Fe firm to produce enriched U commercially

Thor-Westcliffe Research, Inc., Santa Fe, N. M., has asked AEC for the necessary licenses to go into production of enriched uranium with a prototype gas-centrifuge facility near Pittsburg, Kan., early in 1960. Estimated throughput of the prototype would be 6 gm/min uranium hexafluoride (UF_6) feed material. It would be the first privately-owned uranium-isotope separations plant in the U. S. Its first customer may be Spencer Chemical (*see page 27*).

Officials of the company said they have negotiated an exclusive North American processing and patent arrangement with Prof. Wilhelm Groth of Bonn Univ., Germany (NU, June '59, 23), who is "the only man in the free world" successful in separating the isotopes of uranium with a non-gaseous-diffusion process. Seven of Groth's gas centrifuges have been ordered, the firm said, for installation in a 4-2-1 cascade system.

Major goal is full-scale commercial production, sometime in 1961, of 2.1–2.5%-enriched U at an annual rate of about 50,000 kg. Licensing clearances sought from AEC include: one to possess UF_6; one to produce enriched-U; one to build the facility; and one to import the centrifuges. The company said there was no question that it could produce cheaper enriched U than AEC.

NS *Savannah:* Rickover Reviews, McCone Reassures

"There will be no land-based prototype of the *Savannah*. Nor will the *Savannah* be reassigned to the Naval Reactors branch."

This was the reaction of AEC Chairman John A. McCone last month to a flurry of excitement in industry and government over a special review of NS *Savannah*—world's first nuclear merchant ship—by Rear Admiral Hyman Rickover and his staff of the Naval Reactors branch at AEC.

McCone himself had ordered the Rickover review with the relatively harmless aim of assuring that Richard Godwin, chief of the AEC/Maritime Administration group building *Savannah*, had available to him all the lessons learned in the naval reactor program (NU, Sept. '59, 73).

When Rickover and his aides responded in August with a full-fledged critique of the *Savannah* project, the rumors began to fly, among them: "Rickover is trying to take over the *Savannah* . . . Rickover is demanding construction of a reactor prototype before the *Savannah* is allowed to go to sea . . . Rickover is demanding a switch to the Navy way of building nuclear-propelled ships."

McCone and other AEC officials indicated that Rickover's commentary actually fell somewhat short of these extremes. However, his criticism swept over *Savannah's* containment philosophy (putting the entire reactor system into a containment envelope produced a power plant that was too complicated, he said); into the core itself (Rickover gives low-enrichment uranium-oxide short shrift); and encompassed, as well, the control-rod drive system (boron steel allegedly not adequate) and buffer seal system (Rickover prefers canned-motor pumps).

However, none of the critique went to the question of the ship's safety.

Of Savannah's containment, Oak Ridge National Laboratory had this to say after a review completed early last month: "The design and installation of the nuclear plant aboard the NS *Savannah* has provided a degree of containment which is unexcelled by any reactor in existence." ORNL pointed to Savannah's reactor-in-the-bottle design and the negative pressure in the containment envelope as "the two most effective containment techniques yet devised."

At this stage in *Savannah's* construction—she is scheduled to be completed next spring—changes reflecting all the Rickover criticisms would delay her completion for many months and increase her cost considerably. Moreover, she would have then little value as the prototype for a nuclear merchant fleet.

Not Likely

In an interview with NUCLEONICS, however, the key Commissioner in the final decision on the extent of Rickover's influence—McCone—made it clear that he would not accept an erosion of the philosophy underlying *Savannah:* to put on the high seas a nuclear merchant ship built and operated strictly in accordance with commercial practices, consistent with safety. He expressed confidence that Reactor Development chief Frank Pittman, who has been reviewing both the Rickover critique and the rebuttal by Godwin, would find that changes can be made on the basis of naval-reactor experience to increase *Savannah's* reliability.

But, McCone said, such a basic change in *Savannah* as a switch to a highly-enriched core would demonstrate "absolutely nothing of significance to the shipping industry."

"There is a big and important difference between naval-ship construction and merchant-ship construction," McCone emphasized as a man experienced with both (NU, July '58, 20). "The decision was rightfully made [at the start] that the *Savannah* would be built by a merchant-ship branch at AEC in conjunction with the Maritime Administration—rather than the Naval Reactors branch.

Possible Modifications

Improvements based on naval experience that might seriously be considered for *Savannah*, in McCone's view, could fall in these areas: shielding, instrumentation, ease of maintenance at sea, and control techniques.

The Pittman evaluation, with any recommended changes, was to arrive on McCone's desk around the end of September. The Commission was expected to complete its review of Pittman's report shortly thereafter.

"When it does," McCone commented, "I will be satisfied that the *Savannah* will reflect not only the very fine engineering of its contractors [Babcock and Wilcox for the reactor system, New York Shipbuilding Corp. for the ship] but also the extensive experience of the Naval group—to the extent that experience is applicable to merchant-ship construction."

Work Moving Along

Savannah is now being completed in a wet-dock at the Camden, N. J., yards of New York Shipbuilding Corp. As of Sept. 1, her hull was 90% completed, her propulsion plant 32% assembled. She is scheduled to have her core loaded in April, with criticality to follow in May or June.

New naval reactor, NCR, goes to KAPL

The $18.5-million natural circulation reactor project was awarded to Knolls Atomic Power Lab operated by General Electric, AEC announced last month. The NCR is a pressurized-water reactor with nucleate boiling; its natural convection circulation would eliminate pumps, thus ending a source of troublesome noise on submarines, as well as simplifying the plant (NU, Sept. '59, 23, 81).

Lenin goes to sea

The Soviet icebreaker *Lenin*, world's first nuclear-propelled surface ship, sailed on her maiden trial voyage from Leningrad Sept. 15, Tass news agency reported in Moscow.

Eight more sub cores ordered

AEC has ordered eight additional S5W cores for nuclear submarines. Three went to M&C Nuclear, three to Olin Matheson, two to Babcock & Wilcox.

Dresden Nears Completion 6 Months Ahead of Time

The nation's first fully-commercial large-scale nuclear power plant, the 180-Mw(e) Dresden boiling water reactor, is nearing completion six months ahead of schedule.

An application to AEC for an operating license was postponed from Sept. 2 to Sept. 23 because of a technicality: the requirement in the regulations that a plant be certified completed in all respects for fuel loading before an operating license can be granted.

Fuel loading start at Dresden was scheduled to begin Oct. 1. Turbine run-in and balancing tests were made in mid-September, using auxiliary steam from railroad-flat-car-mounted boilers; in fact the intermediate turbine rotor has been shipped back to Schenectady to repair a packing sleeve causing vibration. Critical tests with the head off—for void and temperature coefficients, flux distribution and rod calibration—will take 6–10 weeks. Starting with 28 of the total 488 fuel elements, the minimum critical mass, they will proceed in four stages to full loading.

Then, with the vessel head in place, power testing will begin with stepwise (maximum step 10%) increases in power. Full power will be reached after 3–4 months; then full power must be demonstrated for 1–2 months before Commonwealth Edison accepts the plant. Dedication is scheduled to be about June 1, 1960. It is interesting to note that the warranty determination will not begin until five years after acceptance.

Commissioner Vance Dies

Harold S. Vance, an AEC commissioner for four years, died Aug. 31 at Walter Reed Hospital, Washington, D. C. The 69-year-old former automobile executive was in his last year of a five-year term expiring June 30, 1960. His death, from acute pneumonia, followed an abdominal operation. His death again leaves the Commission shorthanded, just after John Williams' confirmation had brought it to full strength.

Yemelyanov, McCone Agree On Stepped-up Exchanges

Vasily Yemelyanov, nearest man to a Russian counterpart of AEC Chairman John McCone, agreed at a meeting with McCone in Washington last month on two goals for the U. S. and U. S. S. R.: 1. an increase in the exchange of information and scientists in the peaceful nuclear field; and 2. fullest possible support of the International Atomic Energy Agency as a repository and disseminator of information on the peaceful atom.

The two leaders held "preliminary" talks within hours after Yemelyanov debarked from the plane which brought Russian Premier Nikita Krushchev from Moscow Sept. 15. Further Yemelyanov-McCone talks looking toward implementation of the goals were scheduled in late September.

Army Food Program Nears End of Review

The Army Food Irradiation Program (NU, Aug. '59, 17) last month neared completion of a full-fledged Pentagon review. With the induced-irradiation bugaboo apparently settled to everyone's satisfaction the Army was asking itself whether the present level of support for the program was justified. Among other things, the program was competing with other supply-and-logistics-type programs for hardware, research, and development funds.

Congress Passes Fuel Bill

Congress last month gave AEC permission to enter into long-term agreements for the supply of certain services—primarily fuel reprocessing—to holders of materials licenses. Before the Congressional action such agreements were restricted to facility licensees (reactors, etc.).

SENN liability agreement, loan effected

General Electric and Italy's SENN syndicate signed their definitive contract covering the 150-Mw(e) boiling water reactor GE will build in southern Italy on Sept. 9. It completes a preliminary agreement signed Feb. 4. The contract disposes of the troublesome third-party liability issue by providing that if the OEEC liability convention is not completed by the time the reactor is ready to load fuel, the fuel will not be loaded. Signing of the contract clears the way for beginning of heavy construction at the site (preparatory work has been under way since March). The contract calls for beginning of operation 47 months after signing.

Also last month, the World Bank completed negotiations on a $40-million loan for construction of the SENN reactor. The Bank's first loan for a nuclear project, it will cover about 60% of the estimated $66.4-million cost of the plant. It is for a 20-year term, with 6% interest and amortization to start in 1964.

AEC, Duquesne at odds on Shippingport expansion

AEC Chairman John McCone reported to JCAE at end-August that the Commission has run into trouble in its attempt to persuade Duquesne Light Co. to supply additional generating facilities at Shippingport. AEC had asked Duquesne to boost capacity from 100 Mw(e) to 175 Mw to use the heat from a proposed 150-Mw(e) core. Duquesne's terms and conditions for adding the estimated $15-million in equipment were handed to AEC in May. In June, an AEC task force began an evaluation of the proposal and, according to McCone, found problems "which must be resolved before a satisfactory arrangement can be worked out."

McCone has told Congress and, more recently, NUCLEONICS, that AEC will not go ahead with the 150-Mw core for Shippingport unless Duquesne puts in the generating facilities.

AEC Status Reports for 10-Year Reactor Blueprint Claim 8.8-Mill Power for BWR and PWR Concepts

Reports on the status and prospects of the eight major reactor concepts under development in the U. S. show that pressurized- and boiling-water reactors, built with current know-how, could deliver electricity at 8.8 mills in the most feasible size closest to 300 Mw(e).

Except for the organic-moderated concept, PWR and BWR made the best economic showing in "current status" reports submitted to AEC's Division of Reactor Development (DRD) in July. It was estimated that a 300-Mw organic reactor could produce 7.1-mill electricity but this cost was based on fuel-element technology not yet demonstrated. Other cost estimates ranged from 9–10 mills for a 400-Mw(e) heavy-water reactor to 14.3 mills for a fast-breeder built by 1961.

The reports were ordered by DRD early in June as the first phase of a 6-months' effort to draw-up a blueprint for achieving economic power in the U. S. within ten years (NU, July '59, 17). An initial version of the blueprint was completed by the AEC staff last month and a final version will be completed before the end of the year.

Purpose of the summary was to normalize cost estimates, postulate improvements needed, and estimate spending needed to develop each concept's potential. The summary will be particularly useful to AEC this fall in preparing its budget estimates for fiscal 1961.

After further refinement of the summary, the staff will draw up a suggested program of reactor development in terms of the 10-year goals. About the end of the year the final version may be submitted to an ad hoc advisory to AEC for further appraisal. Ultimately, AEC expects to present the program to Congress during the annual 202 hearings on state of the atom.

No. 1: BWR Superheat?

The initial summary, it is understood, nominates boiling-water with integral superheat as the No. 1 candidate for achieving economic nuclear power production in high cost areas of the U. S. by 1965. As of the moment, it is felt, pressurized-water has a slight edge on boiling-water. But, over the next few years, the better potential for reducing costs appears to lie with BWR or with a hybrid BWR-PWR which incorporates the best features of both, including integral superheat.

Nuclear Power Cost: Closing the Gap?

Type	*Size Mw(e)*	*Power Cost mills/kwh*
PWR	*281*	*8.8*
BWR	*320*	*8.8*
Heavy water	*400*	*9–10*
Fast breeder	*300 (1965)*	*8.0*
Thermal breeder	*300 (196?)*	*9.1*
Sodium graphite	*300 (196?)*	*12.35*
Organic	*300 (196?)*	*7.1*
Gas coolant	*n. a.*	*n. a.*

Making "conservative" allowances for technological advances, for reductions in construction and fuel-fabrication costs, and for a decrease of about 25% in the cost of uranium-235 (*see box below*), AEC officials who worked on the initial blueprint estimate that light-water reactors may be able to deliver electricity for less than 6 mills by AEC's "deadline" for achieving economic nuclear power in the U. S.—1968.

In terms of meeting this political, rather than technological, goal they rate heavy-water, sodium-graphite and organic-moderated reactors behind the light-water concepts and—even farther back—gas-cooled reactors. The last concept, it is felt, will continue to face the obstacle which had held it back in the U. S. until just recently; that is, high capital costs.

Economics of U. S. Reactors

The eight reports on current reactor capability represent a hard-nosed effort by DRD's evaluations branch (the authors of the interim blueprint) to get an unbiased picture of U. S. reactor economics. Strict ground rules on such comparative factors as size, technology and timing were laid down to the eight groups preparing the reports; each group was encouraged to consult all others in the field who might have something to contribute; and the reports were returned for rewriting when there was a question of conforming to the ground rules.

In addition the evaluations task force had considerable help in drawing up the interim report from AEC people at national labs and elsewhere. Sargent & Lundy was called in also to collate the status reports and compare their economics to a hypothetical, fossil-fueled plant completed in an "average" area of the U. S. before 1965. Highlights of the eight reports:

PWR (written by Westinghouse)

Costs. Estimates for five pressurized-water reactors: a 25-Mw(e) plant would cost $17.3-million to build now, would produce electricity for 24.1 mills/kwh; 54 Mw, $24.2-million to build, with 16.1-mill power; 171-Mw, $49.1-million and 10.2 mills; 228-Mw, $58.1-million and 9.3 mills; 281-Mw, $66.6-million and 8.8 mills.

Technology. Problem areas include reduction of hot-channel factors, the thermal design limitation of no bulk boiling in the core, limits on reactor-vessel size, and limits on total number of heat-transfer loops that may be added to a single vessel.

AEC Staff Backs Enriched-U Price Cut

An AEC staff report recommending reductions in the government's prices for enriched uranium—reportedly an average reduction of 25%—is being submitted to the Commission. The recommendation was made by the Office of Operations Analysis and Forecasting.

If it is adopted by the Commission it would bring AEC's enriched-U price schedule (NU, Jan. '58, 55) more closely into line with the costs of production. AEC sources recently pointed out to NUCLEONICS that Commission costs have been dropping—and show a downward curve into the foreseeable future—at every point of handling from the mining of U ore to the enrichment process.

Enriched-U can be sold abroad but is leased in the U. S. at an annual use charge of 4% of value. The charge represents an estimated ⅛ to ½ the total fuel cost for a power reactor.

As reported in June by Commissioner John Floberg (NU, Sept. '59, 31), AEC is conducting several studies into the realism of nuclear power costs, including fuel. The Commission is also considering the possibility of seeking a change in the law to permit sale of enriched-U in the U. S.

BWR (General Nuclear Eng.)

Costs. Three designs were studied. A 20.3-Mw could deliver 16.4-mill electricity; the General Electric reactor ordered by SENN (160-Mw) is expected to deliver 11.8-mill electricity; and a 320-Mw reactor designed by GE and Ebasco would deliver 8.8-mill electricity.

Technology. There is an urgent need for experimental information leading to practical engineering designs, because uncertainties in physics information have lead to overconservatism in both nuclear and mechanical designs. Other areas needing investigation include reactor stability, power distribution and lattice and neutron-spectrum measurements.

Heavy Water (du Pont)

Costs. Estimated costs for a 400-Mw, nonboiling, D_2O reactor are $330/kw (capital) and 9–10 mills (electricity). Sargent and Lundy, consulted by du Pont, was in agreement that boiling D_2O will eventually produce the best economics among D_2O reactors. Atomic Energy of Canada, also consulted, predicted that 8.5-mill power will come from second- and third-generation reactors.

Technology. Research is required on fuel-element fabrication and irradiation behavior (both oxide and metal show promise) and on methods of detecting and reducing D_2O leakage.

Fast Breeder (Atomic Power Dev.)

Costs. A plant based on the work already done on the Fermi plant at Lagoona Beach, Mich., could operate in 1961 at a power cost of 14.3 mills. Conceptual design of a second-generation Fermi plant (300-Mw) would cost $74.4-million to build, would produce 8-mill electricity and would be completed by 1965. Plutonium-fueled fast breeders could operate in 1965 at a power cost of 9.5 mills, with improvements leading to 6.9-mill power by 1968.

Technology. Much work must be done on plutonium as a fuel. To achieve high utilization of uranium in fast breeders Pu build-up to cycle loss ratio in the blanket should be above 4-to-1. To accomplish this, it appears that blanket elements capable of 4% Pu building up cycle should be developed.

Sodium-graphite (Atomics Intl.)

Costs. Three alternate estimates: 75-Mw plant could produce 19.12-mill power, using a first core of metal-clad fuel elements; the second core for this plant—uranium carbide with stainless-steel cladding —16.6 mills; and a 300-Mw plant with carbide core—12.35 mills.

Technology. Development of a carbide element is the most promising factor for lowering costs. Satisfactory components are available for a sodium system with the exception of a steam generator. Major efforts also required on simplified design, reliability and reduced cost for control elements, valves, pumps, flow meters, etc.

Organic (also Al)

Costs. Three plant sizes—the smallest scaled up from the Piqua design, the others designed in collaboration with Bechtel Corp.: 20-Mw plant, using aluminum-clad metal fuel, would produce 19.7-mill power and cost $12.6-million to build; 75 Mw, using U-oxide clad with aluminum powder, 12 mills and $27.2-million; and 300 Mw, same type core, 7.1 mills, $57.5-million.

Technology. Recent work on OMR fuel elements has been devoted to cladding oxide with aluminum powder. Tests indicate significantly higher strength than aluminum alloys at higher temperatures and satisfactory radiation stability; no full-size elements yet tested, however.

Thermal breeder (Oak Ridge)

Costs. Lack of operating experience with large-scale reactors precludes completely realistic estimates. Three conceptual designs: a 300-Mw thorium breeder reactor station (three two-region reactors) would have power cost of about 9.1 mills; 150-Mw, two-region reactor, 11.2 mills; the 150-Mw reactor abandoned by Pennsylvania Power and Light, 13.24 mills (a 315-Mw version of this plant, 9.9 mills).

Technology. ORNL considers two-region, circulating-fuel reactors most promising thermal breeders of the aqueous homogeneous type. An aqueous-coolant reactor must be operated at high pressures to produce steam at rather low temperatures, compared with current utility practice. Thus ORNL sees superheating as a "must."

Gas-cooled (also ORNL)

Costs. A final report from Oak Ridge National Laboratory was not yet in when the AEC staff drew up its initial report. However, preliminary figures indicated that a 300-Mw(e) plant would produce 12–14-mill power.

States to get new powers, now AEC-held

Legislation permitting AEC to transfer certain regulatory authority to qualified state governments was approved by Congress last month; President Eisenhower was expected to sign it into law before month's end. The states already exercise authority over X-ray and radium applications; the new act adds radioisotopes, source materials (uranium ore, etc.)and special nuclear materials in quantities not sufficient to form a critical mass. AEC was expected to get to work on new regulations opening the way for transfer agreements with state bodies adequately staffed to take on the new responsibilities.

Congress fails to authorize Stanford accelerator

A number of sticky but not insoluble problems has forced a delay of several months at least in the 15-Bev linear accelerator proposed for construction at Stanford Univ. The Joint Committee on Atomic Energy failed to authorize the $105-million project before Congress adjourned this year because of: 1. differences of opinion on arrangements for purchasing the linac's power supply; 2. patent and royalty troubles involving the machine's klystron tubes; and 3. a possible conflict-of-interest in the fact that project director Ed Ginston is board chairman of Varian Associates, a royalty-owner on klystron tubes. AEC will use the next few months to try to clear the way for Congressional authorization early next year.

New Reactor Concepts 'Off and Running' at AEC . . .

They were off and running last month at Germantown, Md.

The event: the Third Semi-annual AEC Steeplechase, sponsored by the Division of Reactor Development and featuring eleven of the nuclear industry's most promising new reactor concepts.

The "horserace," as it is quite accurately referred to by AEC and industry, is a formal, year-old program to consider new reactor ideas for AEC financial support. It has two major elements of the "sport of kings": 1. AEC is literally gambling a few millions dollars annually on long-shot concepts; and 2. the concepts selected are in a never-ending contest with each other.

Winners of AEC contracts so far (*see table*) have been American Radiator and Standard (two concepts—mercury-cooled and variable moderator); Aerojet-General Nucleonics (sulfur-cooled); Babcock & Wilcox (gas suspension); General Electric (modified sodium-graphite); Martin Co. (fluidized bed, organic-cooled); and Sanderson and Porter (pebble bed, gas-cooled). These "winners," however, might better be called "favorites" because they continue to compete with each other and with newer ideas.

Outside Chance

Despite its sporting nickname, the horserace is a serious effort to assure that all in industry who feel they have a promising idea get formal consideration of their proposal by AEC. At the same time, the program introduces an element of chance into the total U. S. reactor effort—the possibility of a "long-shot" breakthrough in reactor economics. The program's philosophy was stated by an AEC official:

"We expect a pretty high percentage of the ideas we accept to fall down and not be renewed. If that doesn't happen, we are either awfully lucky or we are not gambling at all."

This philosophy holds true, as well, for the program's funding. There is no specific amount available for program contracts and it is up to Frank Pittman, director of reactor development, to conjure up the money for concepts recommended to him by his staff.

Two Races Annually

Key dates in the program are Aug. 31 and Feb. 28 each year. These are the semi-annual deadlines for submission of new concepts and review of those already in the program. The latter are reviewed at the first deadline date after expiration of the contract, which may run from 6 to 12 months, depending on the nature of the work. If a contract expires well ahead of a review date, it may be informally extended until the review can be made.

Some 40 concepts have been proposed since the program was formalized (*see table*), including eleven submitted in the most recent race a month ago. AEC has set no formal deadline for action on these latest entries but the hope is to make a decision some time this month; names of the proposers are being withheld pending selection of the winner or winners.

. . . The Current Favorites

	Concept	Amount	Expires
American Radiator	mercury-cooled	$150,000	Oct. 31/59
	variable moderator	168,657	Nov. 15/59
Aerojet-General	sulfur-cooled	73,000	under negotiation
Babcock & Wilcox	gas suspension	185,500	Oct. 30/59
General Electric	Na-graphite	149,720	Dec. 1/59
Martin (extension)	fluidized bed	1,390,000	Dec. 30/60
Sanderson & Porter (extension)	pebble bed	815,000	June 30/60

. . . Left at the Post

First Race (Aug. 31, 1958)

Raytheon—gas-cooled, liquid-metal-fueled
Battelle—sodium hydroxide-cooled and -moderated
Aerojet-General—nitrogen fixation
—advanced-fluid power reactor
AiResearch (Phoenix, Ariz.)—gaseous fueled
ACF—boiling organic
Jackson and Moreland—light water-moderated, gas-cooled
NDA—fast reactor (high-burnup fuel)
—heavy-water, organic
Internuclear Corp.—automatic boiling column
Associated Nucleonics—organic-moderated
AMF Atomics—beryllium oxide, gas-cooled
Technical Research Group—temperature-zoned reactor
—irradiation reactor
Armour Research Foundation—dust-fueled reactor
Fluor Corp.—flowable solids reactor
Hercules Powder Co.—circulating dust (production of chemicals)
Atomic International—high-temperature reactor
—boiling steam superheat with zirconium hydroxide
—direct conversion
Franklin Institute—mixed fluid, closed cycle

Second Race (Feb. 28, 1959)

Grace Research and Development div.—colloidal nuclear fuels
Ionics, Inc.—fuel concept for aqueous homogeneous reactors
Kaiser Engineers—hydrogen-cooled, graphite-moderated
NDA—steam-cooled, fast-breeder
—high conversion ratio reactors
Thiokol Chemical—boiling-water organic reactor
—liquid-cooled and -moderated
Westinghouse—organic-moderated, fluidized-bed

Reactor News

NPG LOOKING AT ADVANCED WATER REACTOR

The Nuclear Power Group, cosponsor of the Dresden Station, has undertaken a joint study with Atomics International of a graphite-moderated, water-cooled, boiling and super-heating power-reactor concept. Preliminary studies made over the past ten months showed sufficient promise, NPG announced, to warrant further study with a manufacturer "to determine if the concept is worth carrying into the research and experimental stages." The study will cost $150,000, to be borne by the two groups; there is no plan now to build a reactor. The concept would have separate channels in the graphite pile for fuel elements, and for metal coolant tubes in which the water would boil and the steam be superheated. For AI this is the first venture into water-cooled power reactors, the firm being associated primarily with sodium-cooled, graphite-moderated and with organic-cooled and -moderated power reactors. NPG, a research organization, has as members seven utilities and the Bechtel Corp. A large power station with four reactors of this type is being built at Sverdlovsk in the Soviet Union (NU, Sept. '59, 90).

COMBUSTION GETS NUCLEAR TEST PLANT

NTP or Nuclear Test Plant, a test reactor able to test full-scale cores of up to 60-Mw(th), was awarded to Combustion Engineering by AEC last month. In a contract arrangement thought to be unprecedented with AEC, Combustion was assigned conceptual design and operation of the reactor, skipping the detailed design and construction stages, which will be subjects of later contracts. The $5-million NTP will be a pressurized-water reactor, designed to permit full-scale testing of prototype reactor cores for military field plants developed jointly by AEC and the Army Corps of Engineers; thus it would eliminate the need for building a separate prototype reactor for each core tested. NTP's design will have maximum flexibility and extensive instrumentation to facilitate testing of cores of varying design and control systems. To be built at the National Reactor Testing Station in Idaho, NTP will generate no power but will dump the heat produced. CE's proposal was winner from among eleven submitted.

PROCESS HEAT JOB TO SARGENT & LUNDY

Sargent & Lundy won the prize—selection by AEC to negotiate a contract to be architect-engineer—on the low-temperature 40-Mw(th) process heat reactor to be built in cooperation with Interior Dept's Office of Saline Water (NU, Aug. '59, 17; Sept., 32).

KAISER GETS MILITARY STUDY

Kaiser Engineers has been awarded a $515,000 AEC contract for a study of the potential use and cost of nuclear power in 5–40 Mw(e) plant sizes at remote military installations in the period 1963–70. The study will cover best reactor type and cheapest of plant construction, including on-site assembly and erection vs plant fabrication with minimum on-site assembly and erection, or off-site construction on a raft or barge. The final report is to be filed with AEC by Feb. 1, 1960.

GIBBS & HILL, AMERICAN-STANDARD SCORE

Gibbs & Hill Inc. was selected by AEC as architect-engineer for the small—16.5–22-Mw(e)—pressurized-water power plant to be built under the Power Demonstration Reactor Program by a public power or co-op utility (NU, May '59, 25). Gibbs & Hill will do the conceptual design of the steam-raising portion, and has an option to do detailed design of the nuclear portion excluding reactor equipment design. . . . **American Standard's** Advanced Technology Laboratories has been awarded three research-development contracts by AEC. Totaling $2-million worth of work, they embrace the variable-moderator reactor concept (NU, April '59, 19); improvement of the irradiation stability of natural-uranium metal; and application of high-temperature spray techniques to form clad ceramic fuel elements. The first will see a complete VMR core tested at Battelle's critical facility; the second, part of AEC's fuel-cycle program, is expected to increase fuel-element life; the third is under the joint Euratom research program.

OTHER AEC CONTRACT NEWS

W. A. Klinger Inc. of Sioux City, Iowa, won a $1,118,689 contract to build a **Metals Process Development Building** at AEC's Ames (Iowa) Laboratory. Ames has done considerable development work for AEC on yttrium and the rare earths. . . . AEC has awarded a contract to put in a road and water line to the site of the 25-Mw(e) **Experimental Gas-Cooled Reactor** (EGCR), formerly called the Kaiser-ACF gas-cooled project. The site is near the Clinch River on Gallaher Bend, 5 mi south of Oak Ridge and 2 mi east of Oak Ridge National Laboratory. . . . **Alco** has obtained a $1,565,000 AEC contract for final design and fabrication of a sodium-to-sodium heat exchanger and sodium-to-water steam generator in AEC's sodium components development program (NU, Aug. '58, 25). . . . AEC gave a $229,579 contract to build a fuel cladding facility at Hanford to Gate City Steel Inc. of Boise, Idaho. . . . AEC also said it would give Buffalo Univ. a construction permit to build its long-planned research reactor, a 1-Mw pool to be built by AMF Atomics.

NO EARTHQUAKE DAMAGE IN NORTHWEST

The sudden earthquake at Hebgen Dam in southwest Montana that took nine lives late in August caused no damage at the National Reactor Testing Station or at Hanford. At NRTS, 150 mi from the epicenter, two reactors were scrammed manually as a precautionary measure—ETR when the operator noticed waves in one leg of the water canal, S1W when the operator saw some pipes swaying. Other reactors, including A1W, OMRE and MTR, continued in operation. None had seismic scram circuits. Intensive building-by-building surveys in the following days disclosed no structural or other damage. At Hanford, four times as far away, the tremors were still noted by instrumentation, but no emergency controls were thrown.

McCONE REPORTS ON PROGRAM PROGRESS

In a comprehensive report to the Joint Committee on Atomic Energy on how the new authorization and appropriations acts were being carried out, AEC Chairman McCone disclosed the following items of interest: In a recent questionnaire sent to small public and co-op utilities, every one indicated a need for **superheated steam.** . . . The **Carolinas-Virginia** project has shifted from a straight tube to a U-tube design for its heavy-water reactor. . . . The Big Rock Point, Mich., reactor GE will build for **Consumers Power Co.** may be accepted as the high-power-density boiling reactor AEC for which is authorized to give research-development aid in fiscal-1960. . . . The Department of Defense has proposed AEC and the Navy jointly install a 20-Mw(e) **power reactor on Guam.**

ROUNDUP

Work Shortage Hits British Consortia as Market Dries Up; Consortia in Red on 1st Plants; Two Merge

For the last two months, signals of near-distress have been heard with increasing frequency from Britain's big atomic energy industry. Some of those observed:

• A government committee reviewing testimony from a wide sector of Britain's atomic power industry reported that the industry is finding it virtually impossible to sell reactors in Europe. The committee said industry witnesses blamed "unfair [U. S.] commercial practices" for the failure, pointing to credit terms offered buyers of British products as comparing unfavorably with those offered by Americans, and saying that U. S. industry could offer special terms including "guarantees that are clearly backed by the U. S. government."

• All five of the consortia building Britain's first four civil atomic power stations will lose money on them, it is believed; two or three have admitted it. They had cut prices on their bids for these prestige-laden jobs, expecting to recoup on the export business that has failed to materialize. Now they admit frankly that the Central Electricity Generating Board will be faced by stiffer bids next time. Thus capital costs will not come down as had been predicted.

• Two of the consortia—Nuclear Power Plant Co. and AEI–John Thompson—are merging. Among the reasons given:

"Too much capacity may have been created in the atomic field for the work available," H. G. Nelson, director of English Electric Co., declared.

"The young and enthusiastic nuclear industry is fast becoming a paper work industry of tenders and quotations," observed Sir George Dowty of the AEI–Thompson group.

• The entire consortium system may be abandoned. CEGB is reportedly considering an end to its system of ordering complete power plants on a turn-key basis, and would then contract separately for components.

LONDON

Due to the unexpected and worsening coal surplus in Europe which has dried up the nuclear market, there is not enough domestic and export business to sustain the five British consortia over the next 5–7 years. That is the simple truth behind the merger of the AEI–John Thompson group with the Nuclear Power Plant Company. And talking to top executives in the nuclear industry NUCLEONICS gathered there are more mergers on the way.

Although the British 6,000-Mw program for 1965 is not likely to be curtailed, it is insufficient alone to occupy the five consortia and the likelihood of further foreign orders for stations of the Calder Hall magnox-canned fuel element type were considered generally unlikely by most of the consortia.

Amalgamation is seen to be in the nation's best interests. It is the only way, NUCLEONICS was repeatedly told, to eliminate the multiplicity of effort in the research, design and development fields. Especially would it obviate the costly futility of five consortia submitting tenders for each power station.

Aggravating this situation is the fact that as stations in the British power program get bigger in the interests of the scale factor, fewer are required. This leaves a longer period between orders without extending the production time, as this is largely independent of size.

Together, these factors make it more and more difficult for the consortia to keep their design teams together over the threatened lean half-decade ahead. To relieve the dilemma, the nuclear industry is pressing the Atomic Energy Authority for a greater share of the design, research and development work on advanced systems, work that has normally been undertaken by the Authority itself. The Authority has persistently complained that scale of its effort has been restricted by the shortage of scientists and engineers, particularly metallurgists, of which Britain is notoriously short. If some of this work were off-loaded, say the consortia, it would considerably speed the tempo of the whole British nuclear research effort as well as exploit the full scientific capacity of the industry.

This arrangement was in fact one of the recommendations made in the fifth report from the Select Committee of Estimates published recently by the AEA. According to industrial spokesmen the proposal is being sympathetically considered.

But apart from amalgamations, there is no evidence of any major split in the existing nuclear groups, nor of anyone pulling out. A spokesman for Babcock & Wilcox, commenting on the recent tie-up with its namesake in the USA, strongly denied to NUCLEONICS that its arrangements with English Electric Co. were anything but 100% sure in the British market. The original agreement between the two companies specifically provided for independent movement in the foreign field. In fact, said this spokesman, the company might soon tie up with the Swiss Brown Boveri firm.

Faith in Gas Firm

NUCLEONICS was assured that neither the B & W tie nor the association announced between the English Electric Co. and Atomics International reflected any loss of faith in the continuing development of the gas-cooled system as a large baseload station.

The totally unexpected coal surplus is said to have come about partly by effects of mechanization of coal output exceeding expectations, partly because mechanization also produces a larger proportion of small coal, more difficult to dispose of except in thermal power stations.

Both have made even more marginal the economic advantages claimed for large nuclear stations. These had already very few applications because they could only be economic as base load stations.

The annual increase in power demand is not likely to overtake the current coal surplus until 1965 at the earliest, by which time advanced gas-cooled systems capable of operating in smaller sizes more economically will have displaced the present type of magnox-clad station. Further sales of the Calder-type station are now put at no more than two in Britain.

American policy in Europe has certainly not helped the British, top-level executives in the industry told NUCLEONICS. For instance American subsidies are regarded generally to have swung the SENN contract away from the British. Elsewhere, think the British, if the promise of U. S. subsidies had not been present, the consortia would have signed up a number of other European contracts before the coal surplus intervened.

World News

Italy Buys 3d Research Unit, from B&W

Babcock & Wilcox of New York has sold a 5-Mw pool to CAMEN (Centro Autonomo Militare Energia Nucleare), Italy's military nuclear research and training center. Midway between Leghorn and Pisa, it will be used to train engineering students from the Italian Naval Academy at Leghorn and Pisa Univ. Italy's sixth research reactor, it will start up early in 1961.

Italy's SORIN Reactor Critical

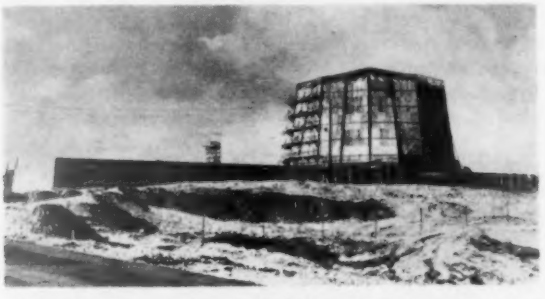
Europe's second privately-owned reactor (after the AEI–John Thompson Merlin pool at Aldermaston, England) went critical at Saluggia, NE of Turin, Sept. 8. Called "Avogadro," the 1-Mw AMF-built pool belongs to SORIN, a joint subsidiary of Italy's big Fiat (autos, machinery) and Montecatini (chemicals) companies.

Puerto Rican Reactor Starts . . .

At the Mayagüez site of the Puerto Rico Nuclear Center, the island's—and Middle America's—first reactor went critical Aug. 12. The research reactor is an Atomics International solution-type lab reactor.

. . . and Israel's Nears Completion

Israel's first reactor, an AMF Atomics pool type, was nearing completion last month on the sand dunes near



Rishon le Zion. The pool, which will operate at 1 Mw at first, 5 Mw later, will be used for isotope production as well as research.

Baghdad Nuclear Center Reopening

"Frozen" since the Iraqi revolution last year, the Baghdad Pact Nuclear Center was scheduled to be reopened last month. Iraq being no longer a member of the Baghdad Pact group, the center will be called the Central Laboratory for Isotopes and Research Studies, and has been placed under the Iraqi AEC. The center was opened in 1957, largely with British contributions and technical help (NU, May '57, 27). Now the Iraqi AEC has engaged Soviet nuclear physicists to work there and has sent a delegation headed by its chairman, Talaat Shaibani (who is also minister of planning), to Russia to seek Soviet equipment for the center. The two nations concluded an agreement for atomic cooperation—even broader than that between Russia and Egypt—and the Soviet pledged to build a 2-Mw research reactor at the Baghdad lab.

Sumitomo to Make Fuel Elements in Japan

The Sumitomo nuclear energy group is planning to enter production of fuel elements and has reached a basic agreement with Sylcor on rights to its induction technique of processing uranium oxide. Sumitomo had previously entered an agreement with Degussa of Germany on natural-uranium refining, and is developing a method said to be unique for making natural U bars with high-temperature and gamma rays. Sumitomo has been determinedly pushing into the fuel field at a time when Mitsubishi, Mitsui and some of the other big Japanese industrial groups are concentrating on importing nuclear equipment.

Austria Starts Second Reactor

Ground was broken last month for Austria's second reactor, a 100-kw General Atomic Triga, to be built at a new $2.3-million National Atom Institute near the southeastern edge of Vienna. The institute will be under the Vienna Polytechnic University.

Site Set for Big Canadian A-Plant

The eastern shore of Lake Huron, 9 mi N of Kincardine (170 mi NE of Detroit), is the site chosen for Canada's $60-million, 200-Mw(e) CANDU reactor plant (NU, Aug. '59, 23). The 2,300-acre site has yet to be approved by the Atomic Energy Control Board.

East German, Czech Milestones

The main laboratory building of East Germany's Rossendorf nuclear center, a short-lived-isotope lab, was officially opened. Only a hot-chemistry building, slated for 1963 completion, remains unfinished. . . . East Germany's first betatron, a 10-Mev unit, was completed at Dresden recently; as also East Germany's first beta thickness gage. . . . The Chirana Works in Prague has started industrial production of a 15-Mev betatron for industrial materials testing, hopes to develop cobalt therapy machines also. . . . Also in Czechoslovakia, a reactor simulator has been completed at Brno.

Brazil Starts a U-Plant

Ground was broken for Brazil's first uranium processing plant at Pocos de Caldas; production should begin in two years. The plant is being built under French supervision and with some French equipment. A second plant is to be started later this year.

Europe's Electric Supply, Demand Up

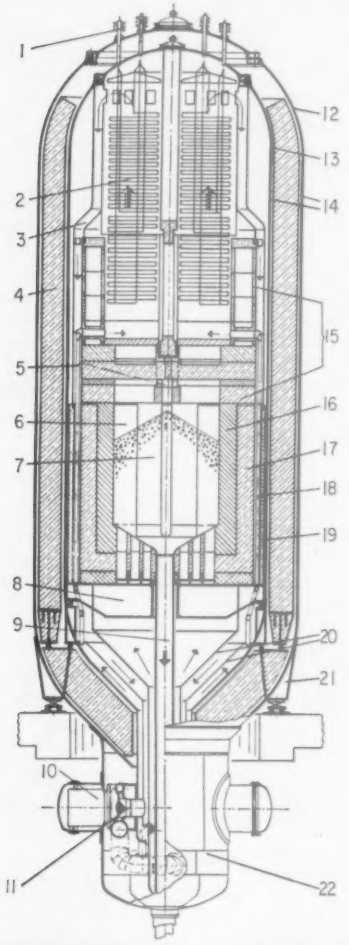
Power consumption in Europe increased 6.5% in 1957 despite slackening economic activity, OEEC reports, and total installed capacity rose from 102,442 to 109,941 Mw. It's forecast that demand will rise 7%/yr for the next five years, and installed capacity will reach 161,600 Mw in 1963. By that year 10–12 nuclear stations totaling 3,250 Mw should be running, OEEC says.

Red China Continues Atomic Advances

A new blast furnace at the Shihchingshan Iron & Steel Plant outside Peiping is being built with cobalt-60 embedded in the inner firebrick wall to detect corrosion, Radio Peiping says. Isotopes released into the molten metal coming out of the furnace will tell engineers when the wall needs overhauling. . . . Faculty members and students of Nankai Univ. in Tientsin have built a small (3-watt) homogeneous reactor. Teachers and students at Szechwan Univ. have built a small (0.06-Mev) cyclotron. An electron static accelerator was built by the Wuhan Institute of Atomic Energy, Wuhan. China's first induction electron accelerator (5 Mev) was "trial produced" last year by teachers and students at Tsinghua Univ., Peiping, China's leading polytechnic institution); apart from a few electron tubes, the equipment was made in China—with Soviet assistance.

German Pebble-Bed Unit Using Off-Shelf Equipment

Construction of Germany's second power reactor, the first built to German designs, will start next April for completion in 1963. The 15-Mw(e) high-temperature pebble-bed, to be built at Jülich by Brown Boveri of Germany and Krupp for the utility combine AVR, will cost $9.5-million, with the German government contributing half; any cost excesses will be shared by Krupp and the government. AVR will use the plant for five years for research in nuclear power plant operation, after which title will pass to the nuclear research center of the state of North Rhine–Westphalia which contributed the site.



Details of the Brown Boveri-Krupp Reactor: (1) ducts for steam-generator tubes; (2) steam generators; (3) coolant-gas baffle plates; (4) biological shield; (5) fuel-ball inlet; (6) lugs for shutdown rods; (7) core; (8) grid; (9) fuel-ball outlet; (10) blower motor; (11) blowers; (12) outer reactor vessel; (13) inner reactor vessel; (14) pressurized gas buffer seal; (15) bridge of carbon bricks; (16) reflector; (17) casing of carbon bricks; (18) bypass tubes; (19) thermal shield; (20) coolant baffle plates; (21) supports; (22) blower dome.

Inquiry by NUCLEONICS as to reactor design brought these details:

Fuel balls will be 6 cm (2.36 in.) dia, containing 3½ gm uranium per ball at 20% enrichment. They will be made by inserting a pressed cylinder of mixed graphite and uranium carbide into graphite balls, which will be closed by a stopper. Irradiation tests are underway at Mol on sample balls.

The plant is designed to use a mixture of 22% (volume) helium, 78% neon as coolant. This can be produced in Germany by liquefying air. Should the U. S. make helium available, the plant can be altered to use pure helium. Coolant temperature is 200° C (392° F) entering, 850° C (1,562° F) leaving the reactor. The design is based on pore-diffusion of volatile fission-products through normal graphite. The coolant is purified continuously, via a bypass, with a combination of molecular sieves and deep-cooled activated carbon. Tests are now being made with relatively gas-permeable graphite.

Reactivity control is accomplished by changing the number of balls in the core; primary-circuit control by changing blower speed; shutdown by four absorbing rods.

Steam at the throttle is 505° C, 70 atm (941° F, 1,030 psi). The plant's 15-Mw(e) capacity is net, with only 450 kw needed for the blowers. The bulk of the equipment is said to be off-the-shelf—identical with that used on comparable conventional machinery. Development work was required for charging and decontamination equipment, and special control and repair devices. Quality and completion guarantees were given for individual parts, but no performance guarantee for the reactor as a whole was made.

The $9.52-million capital cost includes the first charge. Estimates of power cost are not available, but while this pilot plant will certainly not be competitive, it's hoped a 150-Mw(e) scale-up that AVR might later order, would be.

AEC Asks Itself: Retain Campus Reactor Grants?

Should AEC continue its reactor-training grants program beyond the current fiscal year?

AEC itself has raised this question following a 40% cut in the program's appropriation by Congress (reduced from $3.1-million to $1.8-million). The answer may turn on the answer to another, more basic, question: What will the manpower needs of the U. S. reactor program be after 1965?

AEC's Reactor Development div. (DRD) is now attempting an up-to-date estimate of the late-1960 manpower requirement (by AEC and its contractors, by all other government agencies, by industry, and by educational institutions) so it can appraise the necessity for, and extent of, further equipment grants-in-aid to colleges and universities.

Its reappraisal of the grants program comes in midstream, so to speak. Most of the funds spent to date ($11-million) have gone to graduate programs; a sizeable effort for undergraduate training has yet to be mounted.

1957 Predictions

Based on manpower studies conducted in 1957, DRD estimates that 1,960 new reactor engineers and scientists will be needed annually beginning in 1965. Is this "old" figure still a good one? Was it based on a prediction for utilization of nuclear power which is no longer valid? Assuming the 1,960-man estimate still holds, is AEC help vital to an assurance that these people will be trained? AEC wants these answers in connection with its budget request for a reactor-grants program for fiscal year 1961.

AEC grants for the four years through June 30 of next year—for reactors and related equipment—will give U. S. educational institutions capability to train an estimated 800 graduates annually. But there is some feeling within the Commission that this will cover little more than normal attrition (as of 1957 there were 23–25,000 nuclear scientists and engineers with AEC and its contractors, plus 7,000 in non-contractor industry).

There is also AEC concern that failure to invest sufficient funds in reactor training now will hit the U. S. program at a crucial time. From a college's decision to establish a nuclear curriculum to graduation of its first trainees takes 7–9 years.

News in Brief

AEC Renews Contracts with GE, UCC, Mallinckrodt

Two of AEC's major operating contractors—General Electric and Union Carbide—have agreed on extensions of their contracts to June 30, 1964. Union Carbide operates the gaseous diffusion plant at Paducah, Ky., and three facilities at Oak Ridge (the gaseous diffusion and Y-12 production plants and Oak Ridge National Laboratory). Extension of the GE contract covers only Hanford Works, Wash., at an annual fee of $2,196,000; Knolls Atomic Power Laboratory is operated by GE under a separate contract. AEC has also extended to June 30, 1964, its contract with Mallinckrodt Chemical Works for management of the feed material facilities in the St. Louis, Mo., area (primarily Weldon Springs).

Argonne Creates Two New Divisions

Argonne National Laboratory has added two divisions—High Energy Physics and Solid State Science—to the 15 already in existence. "The new divisions," ANL Director Norman Hilberry said, "will allow us to coordinate and emphasize studies of some of the most fascinating and ultimately useful properties of matter. Both will use subatomic particles as probes to determine new facts about the world around us." Acting director of the High Energy Physics div. is Roger Hildebrand, associate laboratory director; Oliver C. Simpson, former associate director, Chemistry div., was named director of the Solid State Science div.

Film Badge Trade Group Under Consideration

A group of commercial film-badge contractors is exploring formation of a trade association to deal with such common problems as standards, legislation, certification, ethics, insurance and government-versus-private operation of film-badge services. Sparking the move is J. J. Steinberg, president, X-Ray Monitoring, who has reported an enthusiastic response from several of the dozen or more firms contacted.

Marquardt Expanding Power-reactor Capability

Expansion of its power-reactor capability—with emphasis on portable and propulsion reactors beyond its present nuclear-ramjet work—has been announced by Marquardt Corp., Van Nuys, Calif. Director of the new Nuclear Systems div. is Alan R. Gruber, who has been chief engineer for Project Pluto, the ramjet project. "Reactors of the type [developing for] for Pluto have some promising non-ramjet applications, particularly in situations which call for a transportable source of power generation," said President Roy E. Marquardt. The firm is exploring military and nonmilitary applications.

GA Given Another $1-Million for Project Orion

The Defense dept. has given General Atomic $1-million in new funds for Project Orion—the project looking to a huge space platform (1,000 tons or more) propelled by small nuclear explosions. A total of $2.4-million has been spent on the effort since the Pentagon first authorized it in mid-1958.

General Instrument Enters Direct Conversion Field

Entry into the direct conversion business—via creation of a Thermoelectric div.—was announced last month by General Instrument Corp. The division will be headed by Melvin Barmat, formerly project manager on SNAP-3 at Martin Co. It expects to employ 50 scientists within a year for work on both nuclear and conventional conversion devices.

UO_2 Plant Brought on Stream by Spencer Chemical

A 100,000 lb/yr uranium-oxide plant was brought on stream last month at Spencer Chemical's Jayhawk Works near Pittsburg, Kan. It will be used primarily to process UO_2 at low enrichment (5% or less); a smaller plant at Jayhawk processes materials of higher enrichments.

Eisenbud Leaves AEC; Hollingsworth Promoted

Merrill Eisenbud, general manager of AEC's New York Operations Office since 1954, has resigned to join the New York University-Bellevue Medical Center as professor of industrial medicine. He will direct a new lab of the Institute of Industrial Medicine for the study of long-range effects of radioactivity on man. . . . Robert E. Hollingsworth, assistant to AEC general manager Alvin Luedecke, has been promoted to deputy general manager. William H. Slaton, former assistant manager at Albuquerque Operations Office, has been named deputy assistant to Luedecke.

Eisenbud Hollingsworth

Euratom Research Board Gets U. S. Recommendations

AEC officials said last month about a dozen proposals of U. S. industry, involving $6.5-million, had been recommended to the U. S.-Euratom research-and-development board for its approval. The AEC review group also recommended rejection of another 30 or so totalling about $3-million. The joint review board was to consider all pending U. S. proposals, as well as those submitted by Euratom interests, at a meeting in mid-September. Meanwhile, it was learned that Amasa Bishop, U. S. scientific representative to Euratom and five of its member countries (all but France), is preparing to leave his post around the end of the year to take an academic job in the U. S.

Mergers: One Off, One On

Victoreen Instrument Co. and **Tenney Engineering** have indefinitely broken off their merger talks (NU, Sept. '59, 159). Chief stumbling block, according to the firms, was failure to agree on future expansion policy; one official saw a possibility of a renewed merger effort later in the year. . . . **Robinson Technical Products**, Teterboro, N. J., has acquired all outstanding stock of **High Vacuum Equipment Corp.**, Hingham, Mass. High Vacuum will be operated as a subsidiary of Robinson.

Industrial Radiation Developments

Baird-Atomic reported a record backlog of $7-million at the end of August and predicted a 50% increase in sales for the year beginning Oct. 1 (to $12-million). Much of the increase, the firm said, would stem from sales of special systems and devices to the government. Meanwhile it was learned that Jack Carlin, president of the recently acquired Atomic Associates and Atomic Accessories, was being given major responsibility at Baird-Atomic for its line of nuclear instruments, under President Davis R. Dewey. . . . **Industrial Nucleonics** has moved into new quarters just outside of Columbus, Ohio (75,000 sq ft). . . . **Vitro Engineering** has been selected by the Navy to design-engineer a $1.7-million high-level radiation lab at the Naval Research Lab.

AEC Aim: Fast Decision On Advanced Test Reactor

AEC last month took the second of three steps expected to lead—later this fall—to a decision on government or private construction of an advanced, high-flux test reactor.

This latest step was circulation of a "quickie" questionnaire to industry designed to show its needs for test-reactor space over the next 5–6 years. Replies were expected in late September from reactor manufacturers, fuel-element fabricators, utility firms, control-system manufacturers, other interested parties.

Earlier, AEC had assigned conceptual design of an advanced test reactor to Phillips Petroleum, which was looking at both a modified version of the Engineering Test Reactor at Idaho and a flux-trap design (with two fuel annuli) of Internuclear Corp. Phillips' recommendation was to be in AEC's hands by Oct. 1.

Within a few days thereafter, AEC expected to complete the third step: a canvass of industry interest in—and conditions for—building the advanced reactor with AEC financial support via long-term contract.

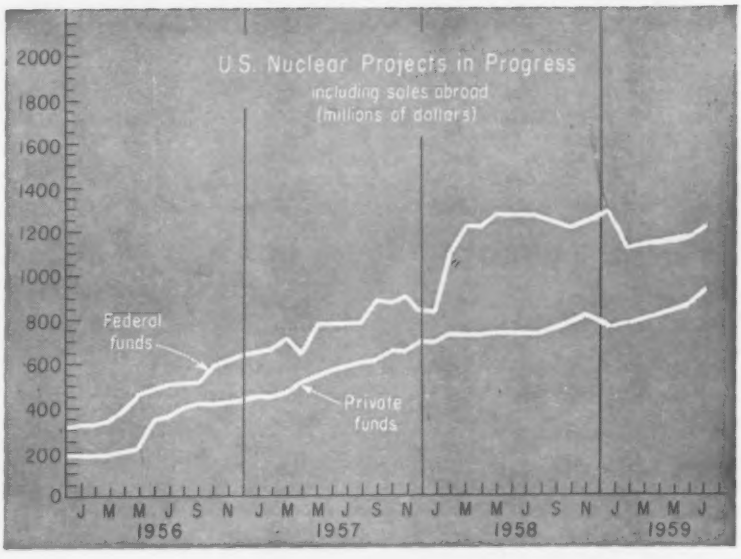
By November, when AEC will be nearing its deadline for making budget commitments for fiscal year 1961, the Commission wants to be in position to decide the basic issue: Government or private construction.

B&W Meets Medium-Flux Needs

This question was decided once this year in favor of industry (NU, Aug. '59, 22), when AEC accepted, as a basis for negotiation, the proposal of Babcock & Wilcox for construction of a variable-power test reactor at Lynchburg, Va. But AEC officials say that this plant (neutron flux 4×10^{14}) will be used to meet medium-flux requirements of the fuel-cycle-development and general-reactor programs. The high-flux requirements of the naval reactors program (up to 2×10^{15}) must be met by the reactor now under consideration.

Meanwhile, an AEC negotiating team was on the road late in August to talk to B&W about its proposed reactor and to Westinghouse (WTR) and General Electric (GETR) about the terms and conditions under which they will lease space.

B&W, it was understood, was seeking a long-term contract from AEC large enough to permit amortization of its reactor in 7–8 years.



NUCLEONICS Statistics of the Month

	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects (10^3)	2,347	37,409	3,638
Proposed construction, privately-owned (10^3)	0	0	0
Contracts awarded, private work (10^3)	0	1,791	4,375
Backlog of private projects (10^3)	285,549	285,000	249
Isotope Use †—			
Applications for isotope use	535	575	548
Cumulative total of isotope users	5,187	5,077	4,089
ORNL shipments (curies)	24,376	8,743	17,618
Public and private export shipments	311	302	272
Employment †—			
AEC employment	6,750	6,785	7,005
Construction and design contractors' employment	9,355	9,878	9,985
Total operating contractors employment	105,928	105,195	103,686
Production workers	51,967	51,930	51,144
Research and development employees	49,217	48,423	46,177
Miscellaneous workers	4,744	4,842	6,365

U. S.-built Reactors ‡—	Operating	Building	Contracted
Power, domestic	1	8	8
Power, for export	0	3	2
Power experiments and pilot plants	6	6	0
Military and naval	10	44	5
Research and test, domestic	61	19	55
Research and test, for export	16	13	9
Total	94	93	79
Foreign-built Reactors ‡—			
Power, domestic	10	28	17
Power, for export	0	2	1
Research and test, domestic	34	11	11
Research and test, for export	8	6	0
Total	52	47	29

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

RCLiac 128 USED ABOARD ATOMIC SUBMARINE TRITON

Compact Reliability for Nuclear Fleet

General Electric scientists and engineers from the Atomic Energy Commission's Knolls Atomic Power Laboratory selected the transistorized RCLiac 128 Channel Scaler-Analyzer for use aboard the world's largest atomic submarine because of its reliability, compact size, low power consumption and ability to measure decay of short-lived nuclides. The RCLiac 128 was used aboard the atomic submarine Triton to perform short half-life studies and other tests. The RCL 256 Channel vacuum tube analyzer had been used in earlier dockside tests.

RCL instruments are found wherever reliability is important. The transistorized RCLiac 128 has proved particularly useful wherever space is at a premium. RCL vacuum tube analyzers are frequently used in larger quarters. RCL now offers four multi-channel vacuum tube analyzers: RCL 256, RCL 512, RCL 1024, and RCL 2048. Specifications are available for each model.

For complete information on RCL's transistorized and vacuum tube analyzers, write Dept. 110

Rugged, compact RCLiac 128 performs both analyzing and scaling operations.

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High voltage supply

The NUCLEAR DATA analyzer has been designed by Robert W. Schumann, formerly of Argonne National Laboratory, designer of the ANL 1024 channel time analyzer, and the ANL 256 channel pulse height analyzer; and Norman S. Jones, formerly of Radiation Counter Laboratories.

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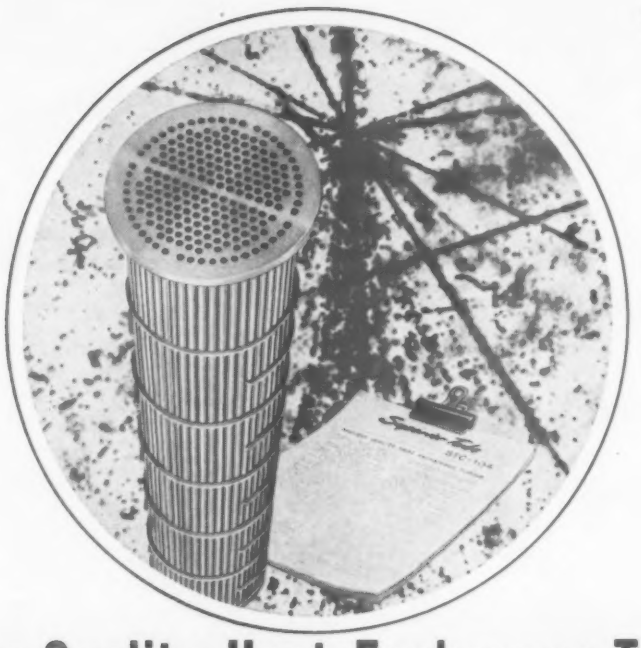

Nuclear-Quality Heat Exchanger Tubing Made to Superior's Specification STC-104

Superior has established a new quality-level for heat exchanger tubing to answer the demand for the high degree of precision required in the nuclear field. Superior's new Specification STC-104 sets new high standards of manufacture for nuclear-quality heat exchanger tubing in five grades of stainless steel in a range of sizes up to 1⅛ in. OD. Here are some of the requirements it stipulates:

MATERIALS. Nuclear-quality heat exchanger tubing shall be produced in AISI types 304, 304L, 316, 347, 348 and other austenitic grades as required.

RAW STOCK QUALITY. Shall be selected from high-quality tubing hollows. A statistical sampling of the tube hollows shall be made to select stock with the most uniform dimensions.

IN-PROCESS INSPECTION. Inspectors shall check work in process for general surface appearance, size and handling procedures to prevent damage to the tubing.

FINISH QUALITY. OD and wall thicknesses shall be held within commercial tolerances unless otherwise specified. Ovality shall be within 3% of the theoretical average OD. Commercial straightness (1 part in 600) shall apply. Dimensional checks shall be made on a 100% basis. Outside surfaces shall be 100% visually inspected.

MECHANICAL PROPERTIES. Shall conform with ranges established by Superior's Metallurgical Department. Typical of the properties given in STC-104 are those shown here for Type 348:

Ultimate Strength (psi)	Yield Strength (psi)	% Elongation in 2 in.
75,000-105,000	30,000-57,000	37 min.

CLEANLINESS. Inside and outside surfaces shall be bright and free from discoloration, grease, dirt, metal shavings, metal particles, and other foreign matter.

FLARING & FLATTENING. Tubing shall be flared with a tool having a 60-degree included angle without cracking or showing flaws. Tubing shall be flattened cold between parallel plates to a distance of three times the wall thickness without cracking or breaking.

SURFACE ROUGHNESS. When specified, surface roughness shall not exceed 63 microinches on either the inside or outside surfaces.

NONDESTRUCTIVE TESTING. A dye penetrant test will be made on a statistical sampling basis. No imperfections greater than 10% of the wall thickness shall be permitted. On tubing with .040 in. wall and heavier, no defects shall exceed .004 in. Tubing which is Eddy Current tested shall be within the above maximum defect level. Mill consultation is required for ultrasonic testing. When specified, it will be done to a .004 in. defect level for tubing ½ in. OD or larger x .040 in. wall and heavier. Hydrostatic testing shall be performed on all tubing.

For full particulars on Nuclear-Quality Heat Exchanger Tubing, write for a copy of Superior Specification STC-104 and also of Data Memorandum #20. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

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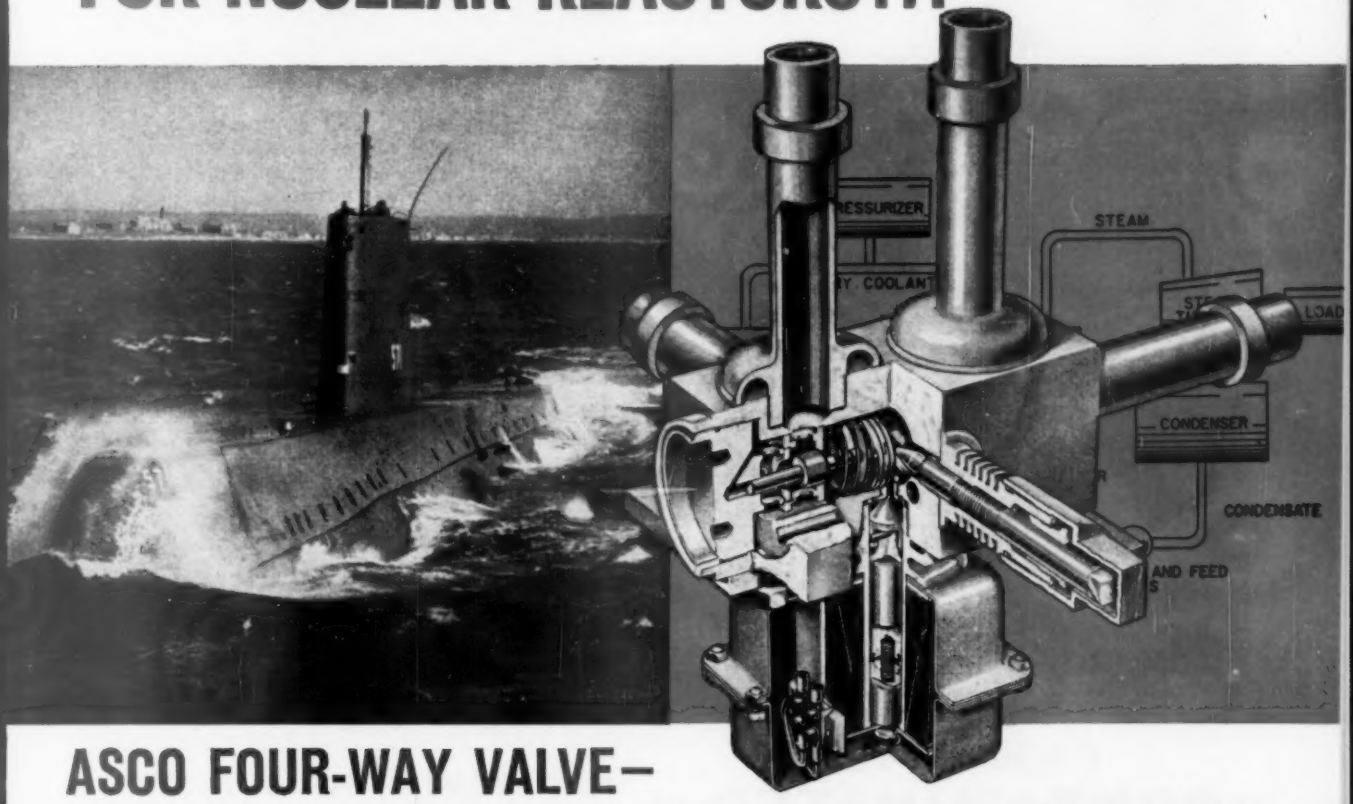

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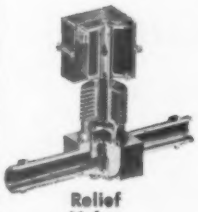

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By-Pass Coolant Valve

Secondary System

2-way Valves

3-way Valves

Instrumentation Control

2-way Valves

3-way Valves

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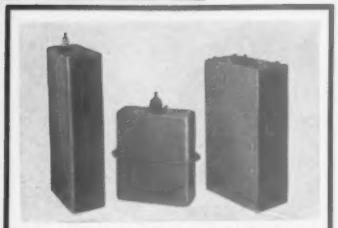

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(IN THE NOVEMBER ISSUE)

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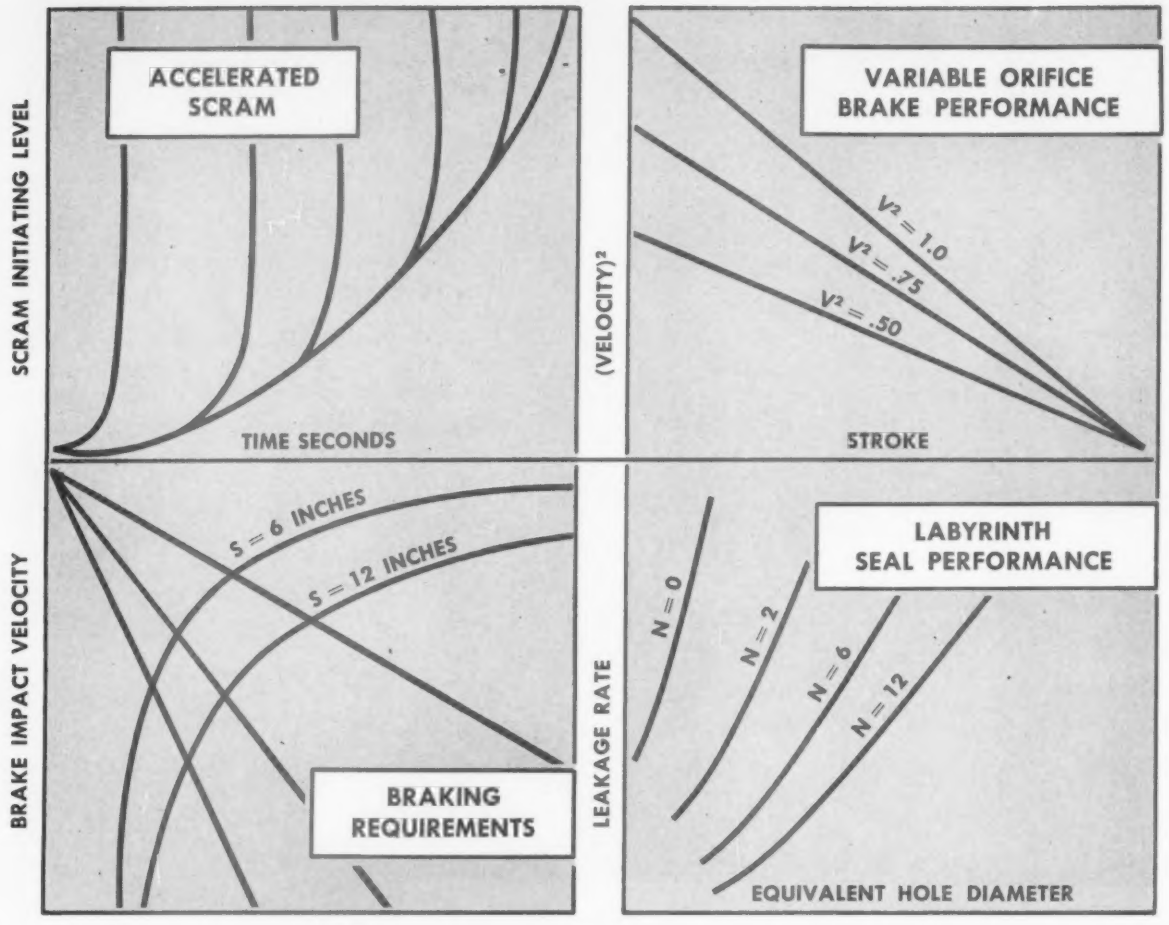

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Control rod drives were first developed by General Mills for use on research reactors. The principal design objectives were faultless dependability and pinpoint precision — achieved at the lowest possible cost. We met these objectives. Since then, custom designs, assuring the same dependability and precision, have been completed for gas cooled and pressurized reactors.

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For specific information, write:

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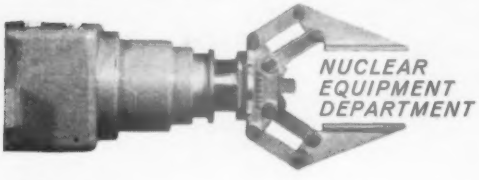

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1. Plug-in, interchangeable modules for ease of maintenance;* 2. self-test and self-monitoring circuitry; 3. simplified design for maximum reliability.

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CURRENT PROJECTS Marine Power Plants • Portable Power Installations • Commercial Central Power Stations

Brochure with data sheets and photographs on request.

Engineers and scientists with experience in solid state electronics interested in joining this expanding program may contact—Manager of Technical Personnel.

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B&W reactor vessel manufactured for the Belgian Thermal Reactor, BR-3, designed by Westinghouse Electric Corporation, Atomic Power Department.

MORE NUCLEAR POWER FOR EUROPE

This is the 14th pressurized water reactor vessel shipped of a total of 34 ordered from The Babcock & Wilcox Company, U.S.A.

B&W's continuing search for improved nuclear products is helping to speed the practical application of nuclear energy throughout the free world. For more information, write The Babcock & Wilcox Company, Barberton, Ohio, U.S.A.

Der 14te von 34 bei The Babcock & Wilcox Company, U.S.A., in Auftrag gegebenen Druckwasserreaktor-Tanks wird verladen. Die fortwährende Forschung der B&W nach besseren Atomprodukten befördert die praktische Anwendung der Atomenergie in der ganzen Welt. Für nähere Auskunft, bitte sich zu wenden an The Babcock & Wilcox Company, Barberton, Ohio, U. S. A.

Le 14ième vaisseau du réacteur à eau sous pression d'une commande totale de 34 unités, passée à la société The Babcock & Wilcox Company, E.U.A., est embarqué.

La recherche constante de B&W pour améliorer les produits nucléaires contribue à activer l'application pratique de l'énergie nucléaire à travers le monde. Pour plus de détails, écrivez à The Babcock & Wilcox Company, Barberton, Ohio, U.S.A.

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BOILER DIVISION

NC-111

Complete nuclear systems, cores, components, fuel elements, nuclear research and development

FACTS you should know about commercial uranium

Outmodes many present metals and methods - safely and at low cost

What is Commercial Uranium?

Commercial (depleted) Uranium—the uranium isotopes remaining after the removal of U-235 (with *radiation exposure about equal to that obtained in watching your TV set*)—possesses many inherent qualities of interest to many industries.

Uranium has many interesting properties.

For example, Davison Uranium has exceptional density —*68% greater than lead* and about equal to gold. This indicates usages as counterweights in aircraft, shipbuilding, tool making industries—wherever high weight and low volume are factors. It alloys readily with many metals including aluminum, chromium, copper, iron, manganese, molybdenum, niobium, nickel, silicon and zirconium. Corrosion resistance is increased when uranium is alloyed with one of these metals. Davison Uranium possesses high tensile strength and low thermal expansion. While fairly hard (Brinnell 240) at room temperature, uranium becomes very malleable as temperature rises. At 1100° F. its hardness drops to about 20.

Is Davison Uranium easy to fabricate?

Davison Uranium may be melted and cast into any desired shape. It may be formed by extrusion, drawing, rolling, swaging, pressing or forging.

You can machine Commercial Uranium with conventional carbide-tipped machine tools, bearing in mind that it has work-hardening characteristics similar to those of stainless steel.

It is necessary to machine uranium under water soluble lubricants. Commercial Uranium has been machined on a number of tools including lathes and automatic screw machines, saws, high-speed mills and centerless and surface grinders.

How about welding?

Success in welding Davison Uranium has been achieved using the Heliarc and shielded arc-consumable electrode process. At this date experiments continue in joining uranium to uranium by brazing or soldering.

How has Commercial Uranium been used?

Present applications include shielding materials, teletherapeutic heads, isotope containers; as counterweights and static balances. And, for many years, as coloring agents and glazes.

Is Davison Uranium safe?

Radiation hazards are minor. AEC tests indicate that ~~*a week's exposure* to depleted~~ Uranium is only about *1/10th to 1/100th* the radiation received from an *ordinary chest X-ray.*

However, just as other heavy metals such as lead are toxic if breathed, care must be exercised to avoid inhalation of uranium dusts. A properly ventilated work area removes this dusting problem.

Must special storage precautions be taken?

Uranium metal (except fines) can be *handled and stored with methods similar to those used with any other massive metal.* Fines, however, are flammable and should be stored under oil or water.

Is Commercial Uranium expensive?

Not at all. For example, in lots of 1400 pounds or more Commercial Uranium is priced at just $4.60 per pound —considerably cheaper than other heavy metals, with the advantage of superior density.

Need more information?

A letter will bring you additional details for the application of Commercial Uranium to your products or processes. Write today to Department A-210, Erwin, Tennessee.

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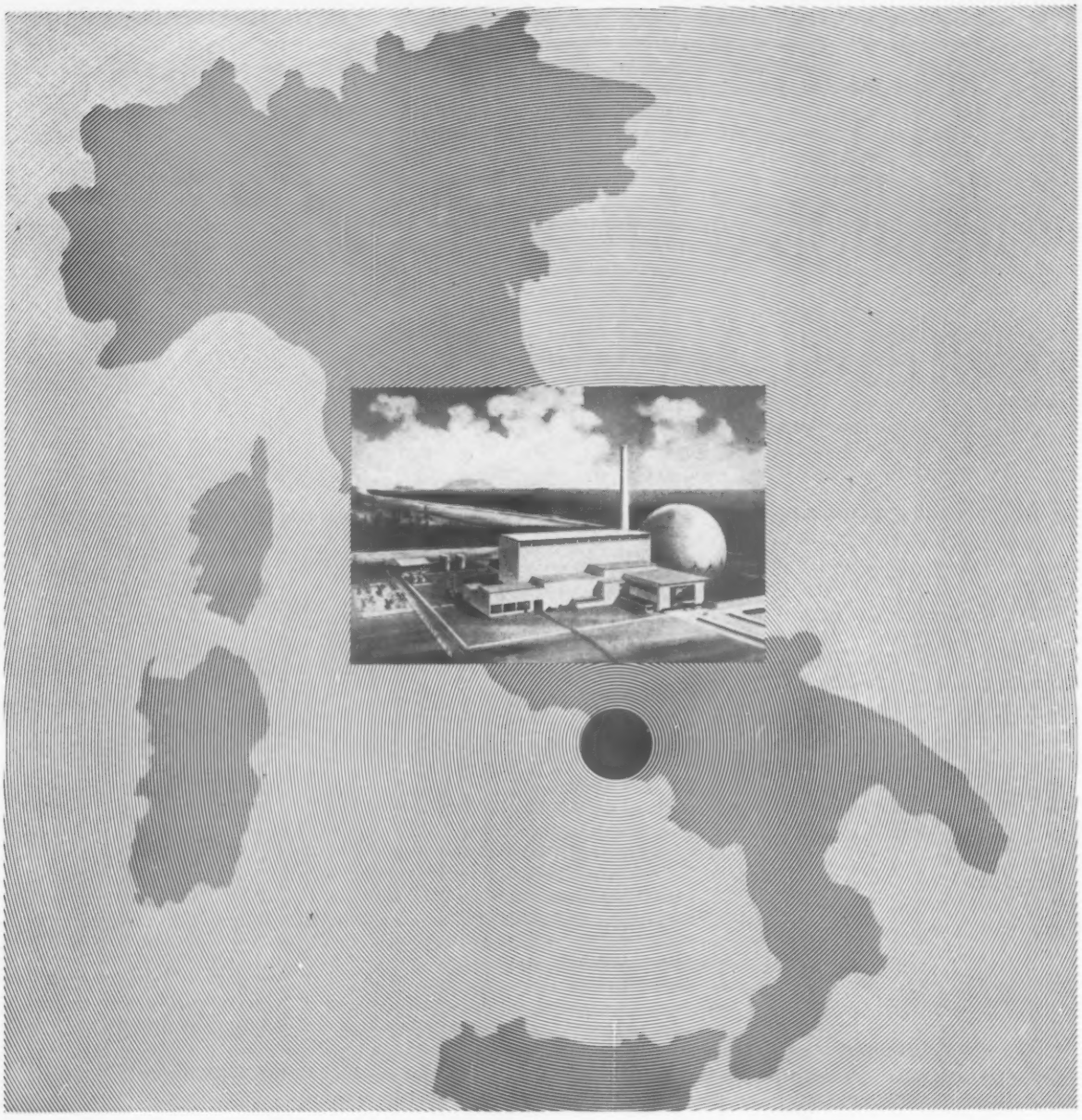

A new atomic power plant for Italy...the SENN plant near Naples. Engineering and construction is being handled by Ebasco. This project is backed by Ebasco's 54-year reputation for outstanding quality in diversified engineering and construction work.

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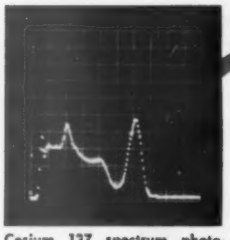
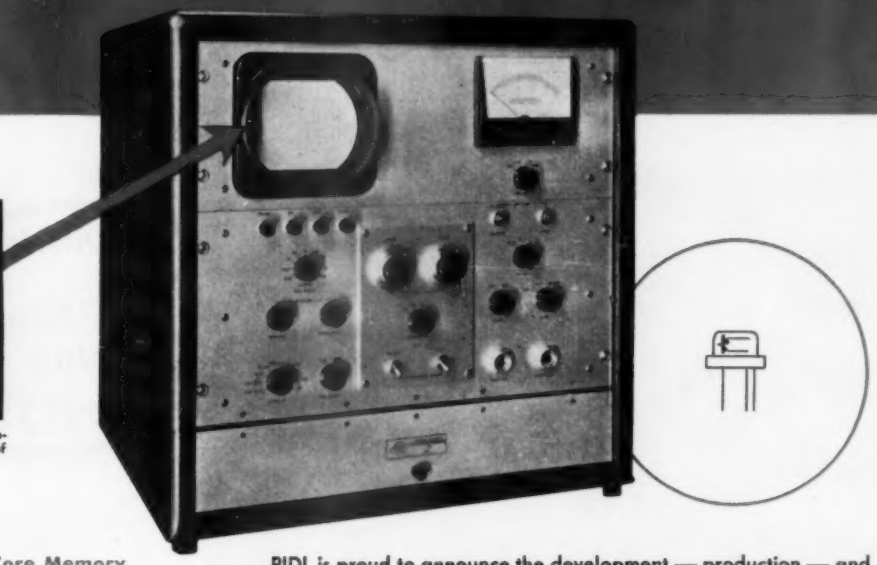
MODEL 34-8
TRANSISTORIZED 200 CHANNEL ANALYZER



Cesium 137 spectrum photographed from CRT display of Model 34-8.



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- Memory Subgrouping
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- Spectrum Transfer Circuit
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- Parallel Coded Decimal Readout
- Multi-Channel Scaler Operation
- 10^5 Count Capacity
- Installation by Factory Engineer
- Course of Instruction Offered

RIDL is proud to announce the development — production — and delivery of the Model 34-8 Transistorized 200 Channel Analyzer. This unit is a **completely new** approach to the field of multi-channel analysis. This new approach, in conjunction with solid-state techniques — i.e., transistors in place of vacuum tubes, printed circuitry, etc. — allows compactness, low power consumption and heat dissipation and high reliability.

The STANDARD Model 34-8 is capable of operation as either a Multi-Channel *Pulse Height* Analyzer or a Multi-Channel Scaler (*Time* Analyzer). There are no extra plug-in modules to purchase in order to perform these separate functions. The change from one analysis mode to another is accomplished by the use of a single toggle switch.

In the Model 34-8, data is stored in the memory in coded decimal form. This, in conjunction with parallel coded decimal readout directly from the data register to the printer, eliminates the need for a 'Binary-to-Decimal Decoder'. The printout speed is therefore limited only by the particular printer used.

The Model 34-8 is another of the NEW line of instruments designed and developed by RIDL. Whatever your instrumentation problem may be, RIDL has the solution. Our staff is always available to answer your inquiries. Write today to Dept. 57 for complete information.

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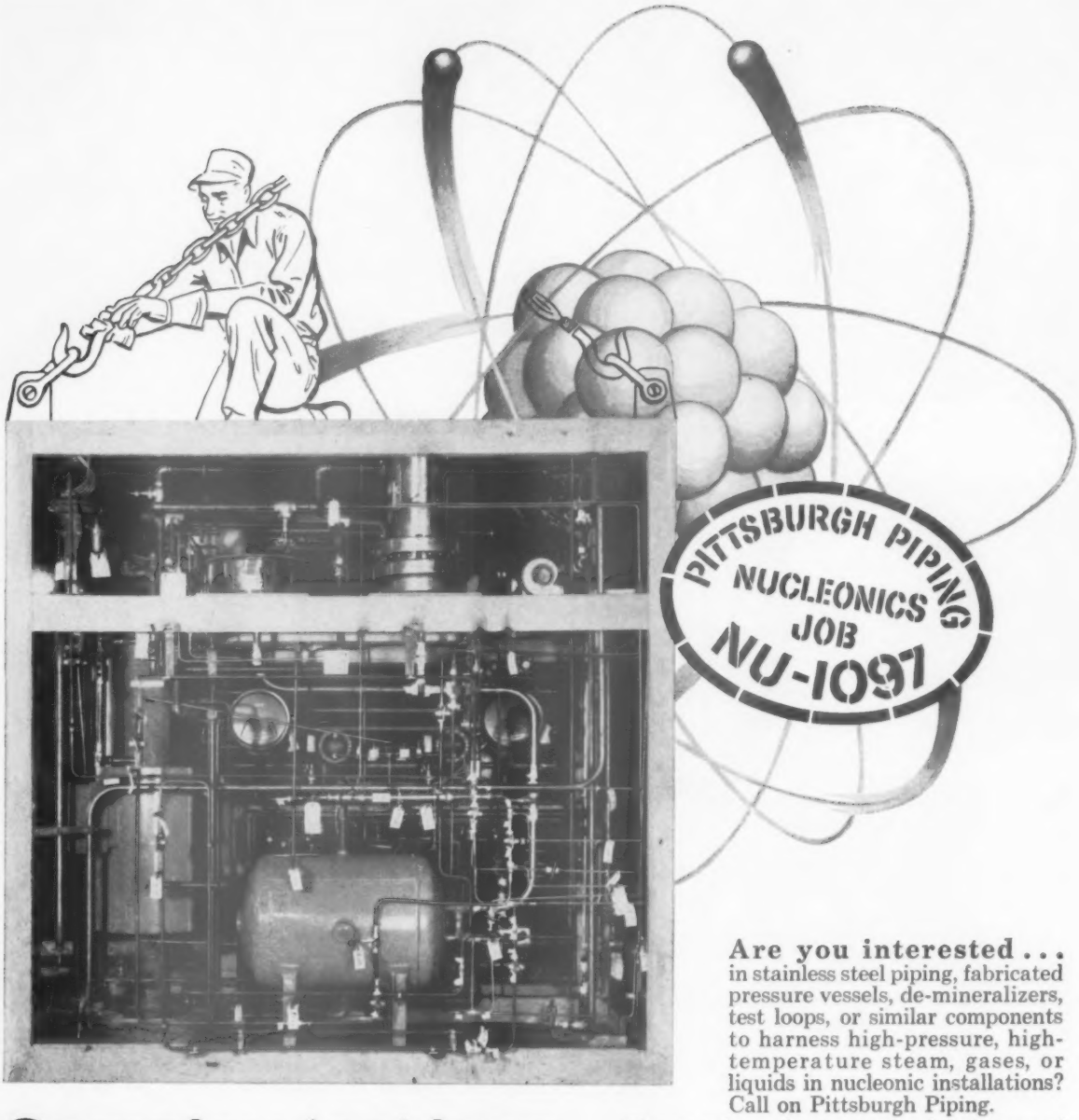

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PP-42

One of the leading figures in nuclear reactor development in this country, J. M. Harrer, MSE, participated in the Geneva Conferences and similar nuclear activities in Norway, France, Italy and Australia. He is Chairman, Chicago Section of the American Nuclear Society, Chairman of the AIEE Subcommittee of Reactor Instrumentation, and a member of 12 other nuclear groups. He is presently Associate Director, Reactor Engineering Division, Argonne National Laboratory which is operated by the University of Chicago for the AEC.

His problem:

To develop an economically practical nuclear power reactor

The name of this scientific American: J. M. Harrer, Argonne National Laboratory

"In our search for an economically feasible nuclear reactor, we have reasoned that if we can learn to bring together the rare elements of human know-how at the right time —and under the right conditions— we'll release a chain reaction of ideas that lead to a successful design." So comments J. M. Harrer, Associate Director of Reactor Engineering, Argonne National Laboratory, Lemont, Ill.

Harrer's emphasis on human resources has produced results. His staff, working with control engineers, has been able to automatically position the reactor control rods which function as throttles in keeping reactor output at the required level. His team has also developed a highly desirable "zero steam bypass" for boiling water reactors which saves the significant percentage of reactor output formerly used as a control "cushion."

Other reactor engineering accomplishments of the Argonne facility include: first significant amount of electric power from a nuclear reactor, first atomic power to light an entire town, first completely integrated breeder reactor . . . as well as basic development for military reactors. Advances such as these bring America much closer to the reality of economical nuclear power.

Leeds & Northrup men work closely with Harrer's team of scientists, converting ideas into controls that do the required job . . . frequently in unexplored areas of the nuclear control science.

Look closely at the many L&N installations in the atomic energy field . . . in any major industry . . . and you'll see the kind of quality which scientifically-minded leaders respect.

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Last year, traffic accidents killed 37,000, injured 1,400,000

. . . and they wasted Five Billion Dollars!

Traffic accidents' human toll is so tragic we sometimes overlook their staggering economic waste. Five Billion Dollars in lost wages, medical expenses, insurance costs and property damage! Your business—every business—shares in this loss. So you have a double interest in helping reduce traffic accidents. And you *can* help! Drive safely and obey the law yourself . . . certainly. But go further. Use your influence to promote safe driving and urge strict law enforcement. To make your efforts more effective, join with others working actively to reduce traffic hazards in your community. *Support your local Safety Council!*

Published in an effort to save lives, in cooperation with the National Safety Council and The Advertising Council.

Allis-Chalmers Greendale research and development center for nuclear power also includes a critical facility of a full-scale mock-up of the Pathfinder reactor.

Allis-Chalmers is growing fast...

in the Nuclear Power business

Allis-Chalmers is growing dynamically in the nuclear field... completely capable of taking projects all the way from "talk-about" to start-up. Here's a special report on Allis-Chalmers broad capabilities and resources.

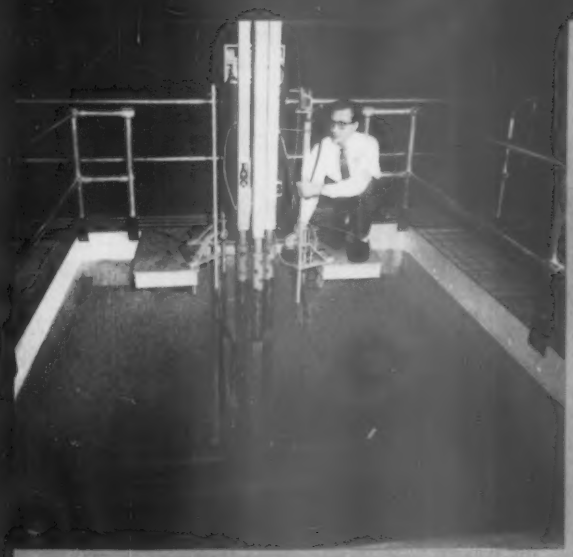
Well known for many accomplishments in the electric power field, Allis-Chalmers has for some time realized that an ever-increasing part of the electric power needs of the future will be supplied by Nuclear Energy.

In order to always stay ahead of this trend, A-C has moved to strengthen its position in the swiftly advancing nuclear reactor field. Most recent evidence of this was the acquisition of the reactor engineering organization and reactor business of ACF Industries.

In this move, A-C added to a competent and experienced nuclear power staff, a group of nuclear scientists and engineers with a distinguished record of accomplishments in the design and construction of reactors both here and abroad.

Combining this outstandingly versatile nuclear reactor know-how and Allis-Chalmers broad electric power equipment experience with vast production facilities provides a vital resource to meet the growing demand of the Atomic Energy industry.

Today, whether your nuclear power plans are at the "talk-about and investigate" stage or are ready for plans and estimates, you should get better acquainted with what Allis-Chalmers can offer. Now turn the page for a look at what A-C has done... and is doing ... for others. Check the wide experience which can be put to work on your problem.



Pool Training-and-Research Reactor. Allis-Chalmers offers a variety of these reactors with operating power levels from 10 kw to 5,000 kw. Can be erected in ordinary buildings and no special utilities are needed. Safe, simple training devices with many standardized components which reduce initial and maintenance costs.

MIT (Massachusetts Institute of Technology). Complete engineering design, construction, and start-up handled by A-C. This 1,000 kw reactor features a thermal column and a medical therapy facility with a water- and boron-filled shutter arrangement.

Built or Building...

unmatched reactor versatility from Allis-Chalmers

R-2 (Atomic Energy Company of Stockholm, Sweden). High-flux research reactor for materials testing, fuel development, and nuclear research. Sea water is used as secondary coolant in cooling system. Allis-Chalmers responsibility also includes supervising construction, installation, and start-up of this 30,000 kw reactor.

AF-NETR (Wright-Patterson Air Force Base, Ohio). Water-cooled and moderated reactor designed and being built by A-C. This 10,000 kw reactor incorporates two large, high-flux irradiation-test cells in which high-altitude pressures and other flight conditions can be simulated.

ERR (Elk River Reactor). Built by A-C as prime contractor for the Rural Cooperative Power Association of Elk River, Minn. This 22,000 kw reactor operates with existing RCPA power plant and will produce steam at same temperature and pressure as that from the existing boilers.

CNRN (Italian National Committee for Nuclear Research, Milan, Italy). Heavy-water research reactor used for neutron diffraction, isotope production, and general irradiation experiments. This 5,000 kw reactor is the first to be purchased for use in the Euratom program.

RCN (Reactor Centrum Nederland, Amsterdam). High-flux materials testing and research reactor designed and being built by A-C near Amsterdam. Reactor vessel is immersed in a pool with concrete walls penetrated by numerous experimental facilities. A-C will start up this 20,000 kw reactor, as well as train the operators.

The nine reactors described on these pages have been built... or are now being built... by the Allis-Chalmers staff of reactor specialists.

Training reactors, research reactors, test reactors, and several types of power reactors... these all have contributed to the broad experience in design, development, erection, operation, and maintenance unique with Allis-Chalmers. New developments swiftly influence existing concepts. That's why it is important that you work with people who have versatile experience, a solid record of accomplishment, and proven creativity . . . in short, the talented Atomic Energy Division of Allis-Chalmers.

New Brochure

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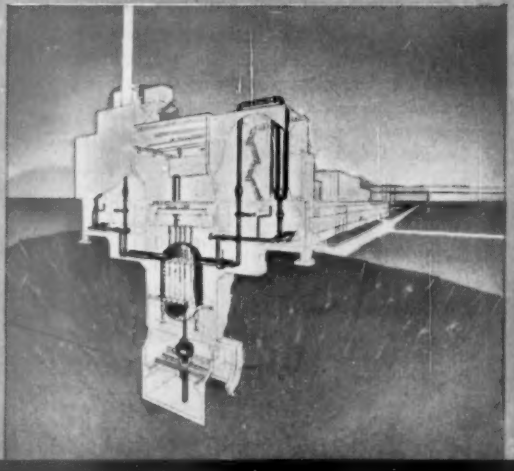
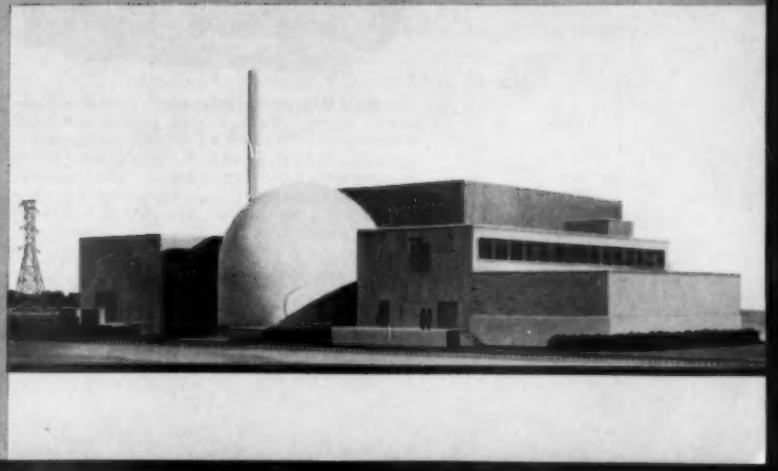
ALLIS-CHALMERS

A-1187-PI

EGCR (Experimental Gas-Cooled Reactor, USAEC). As subcontractor, A-C completed feasibility and optimization studies of prototype and full-scale power reactors using both natural and enriched uranium fuels. Allis-Chalmers also developed and extended analytic techniques for the physics, thermal characteristics, and fuel-element design of gas-cooled reactors. 85 Mwt, Oak Ridge, Tennessee.

CRBR (Northern States Power Company). This 66,000 kw direct-cycle Controlled Recirculation Boiling-water Reactor (CRBR), with internal nuclear superheat, represents an important advance in reactor technology. To be located near Sioux Falls, S. D., this plant is being designed and built by A-C for Northern States Power Company in cooperation with ten other Midwest electric companies.





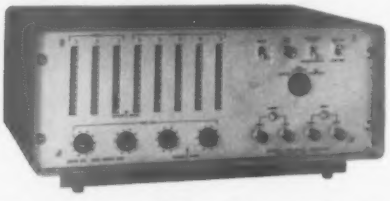
PRACTICAL ACCURACY

The portable CN-110 256-channel pulse analysis system — can be changed from pulse height analysis to time-of-flight to pulsed neutron measurement — or to some special program — simply by interchanging the compact plug-in logic units in the front panel. The basic computer with plug-in weighs only 30 lbs., and can be bench or rack-mounted or carried anywhere in a portable case for laboratory or field work. Power consumption is only 25 watts — needs no auxiliary cooling . . . can be set up for analog, digital or binary readout of various methods.

. . . new portability in TMC instruments

These new instruments from TMC, with completely transistorized circuits and efficient, straightforward design, are the most practical answer to the need for portable yet accurate pulse measurement instruments. Whether in a laboratory or in the field, the extreme reliability, accuracy and compactness of these instruments combine to provide convenient, dependable operation wherever they are set up.

The SG-10A Serviscaler is an extremely economical and portable instrument designed for training or general laboratory use. All-transistor circuits are housed in a 12 lb., 12¼" x 9" x 5¼" package. Continuous high voltage, adjustable from 600 to 1600 volts; resolving time better than 200 μsec; power consumption of only 20 watts. Price is $350.



The No. 220 Data Handling Unit — a logical companion to the CN-110, is both a timer and data-handling unit. During the CN-110's accumulation cycle the 220 can be used for true or live timing, then instantly switched to a manual, semi-, or fully-automatic digital readout cycle (destructive or non-destructive). The compact 220 may be used with various paper tape punching and printing machines.

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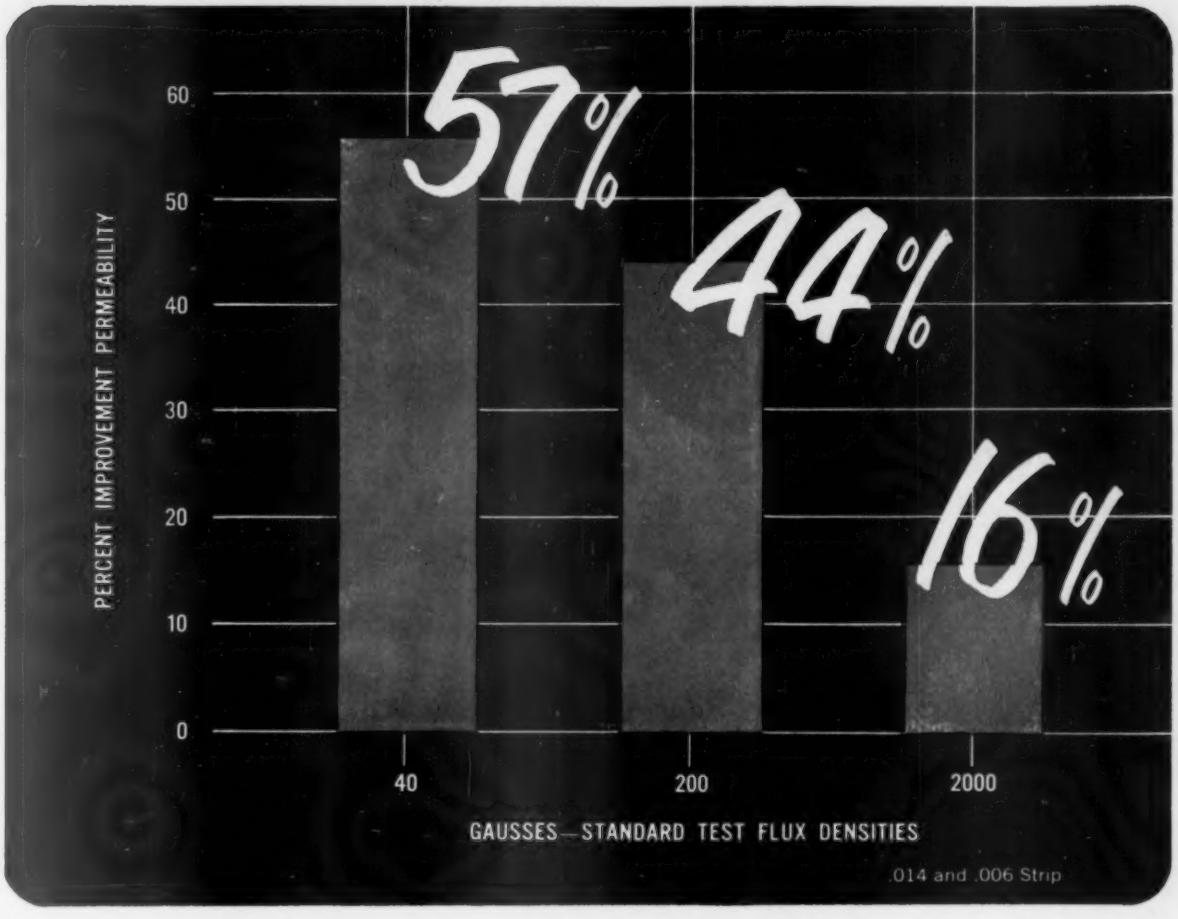

Greater permeability for Allegheny Ludlum's AL-4750...and it's *guaranteed*

promises more consistency, higher predictability for magnetic cores

AL-4750 nickel-iron strip now has higher *guaranteed* permeability values than ever before. For example, at 40 induction gausses AL-4750 now has 57% higher permeability than in the past, using the standard flux density test.

This greater permeability means better consistency and predictability for magnetic core users . . . and allows careful, high performance design.

This improvement in AL-4750 is the result of Allegheny Ludlum's continuing research on electrical alloys and nickel-bearing steels. Moly Permalloy has been similarly improved in permeability. A-L constantly researches silicon steels, including A-L's well-known grain-oriented silicon, Silectron, and other magnetic alloys.

Complete facilities for the fabrication and heat treatment of laminations are available at Allegheny Ludlum. And A-L's technical know-how guarantees you close gage tolerance, uniformity of gage throughout the coil and minimum spread of gage across the coil-width.

If you have a problem on electrical steels, laminations or magnetic material, call A-L for prompt technical assistance. Write for blue sheet EM-16 for complete data on AL-4750. ***Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh 22, Pa. Address Dept.*** *NC-22*

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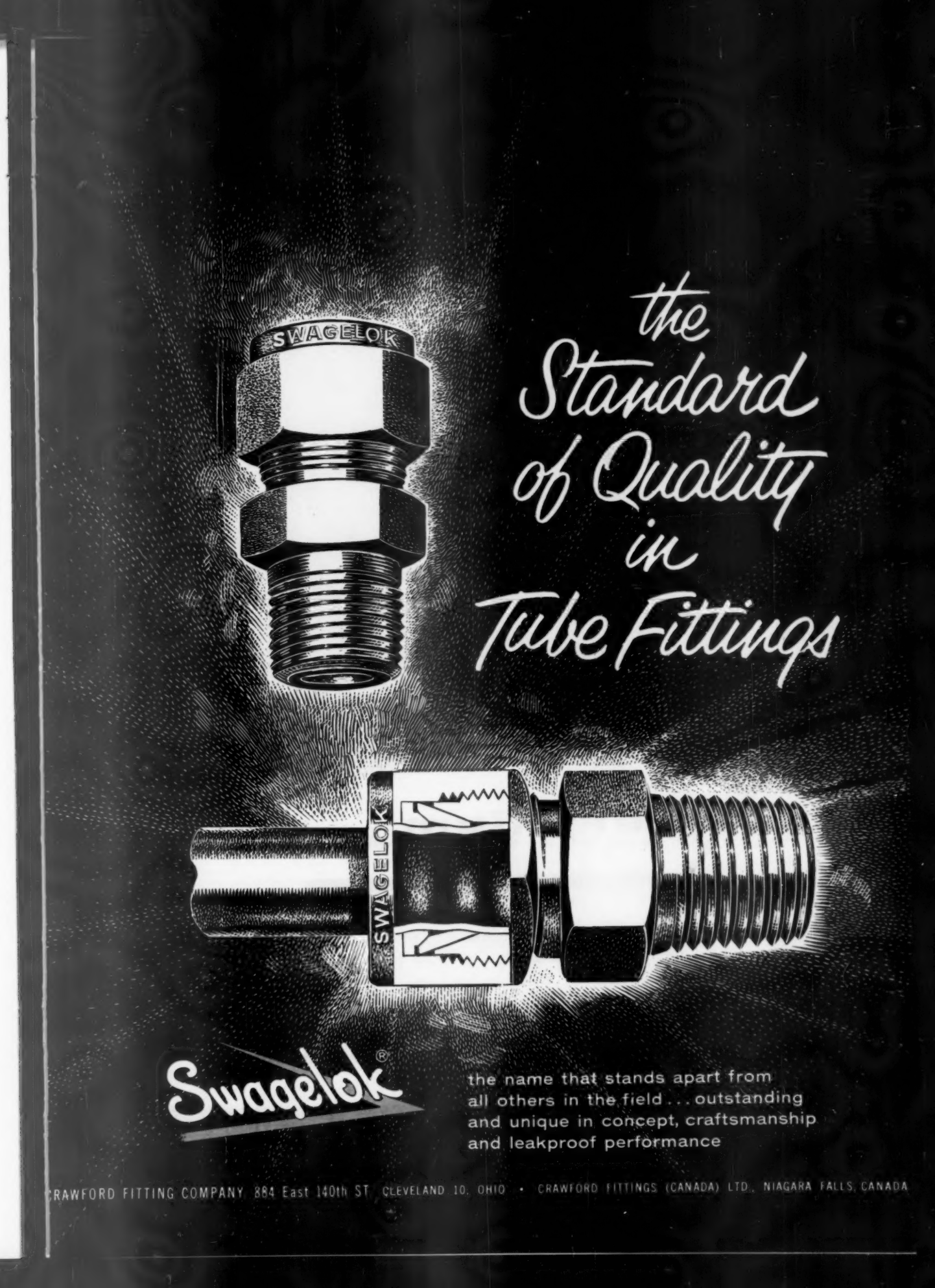
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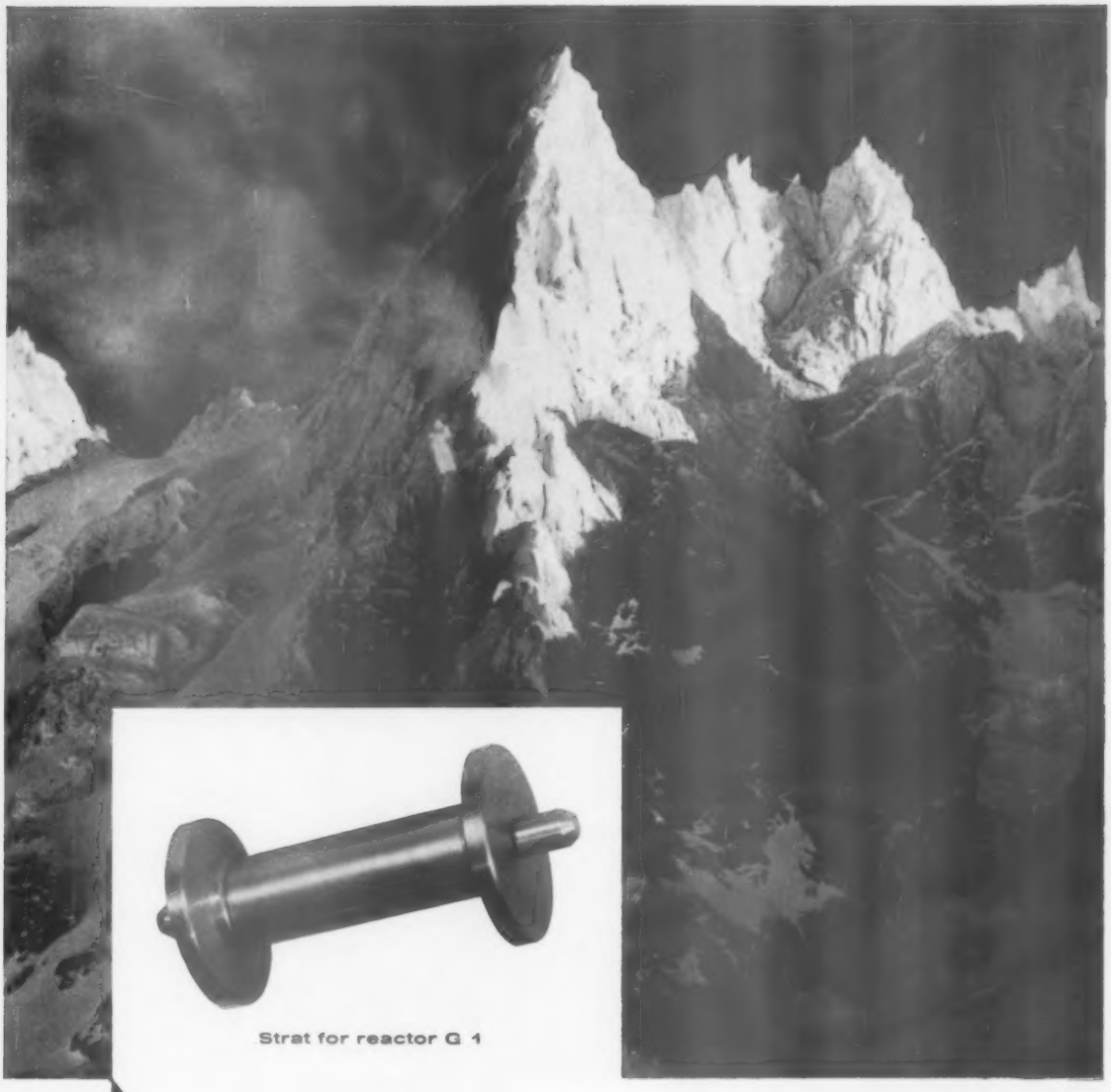

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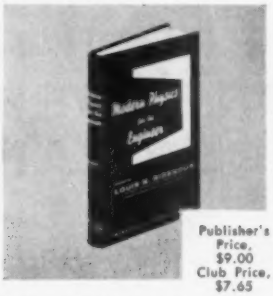

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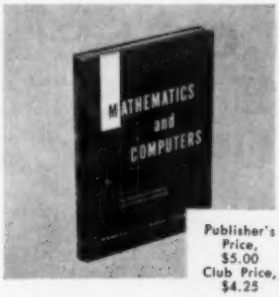

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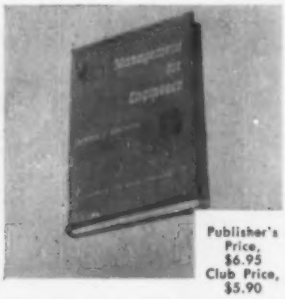

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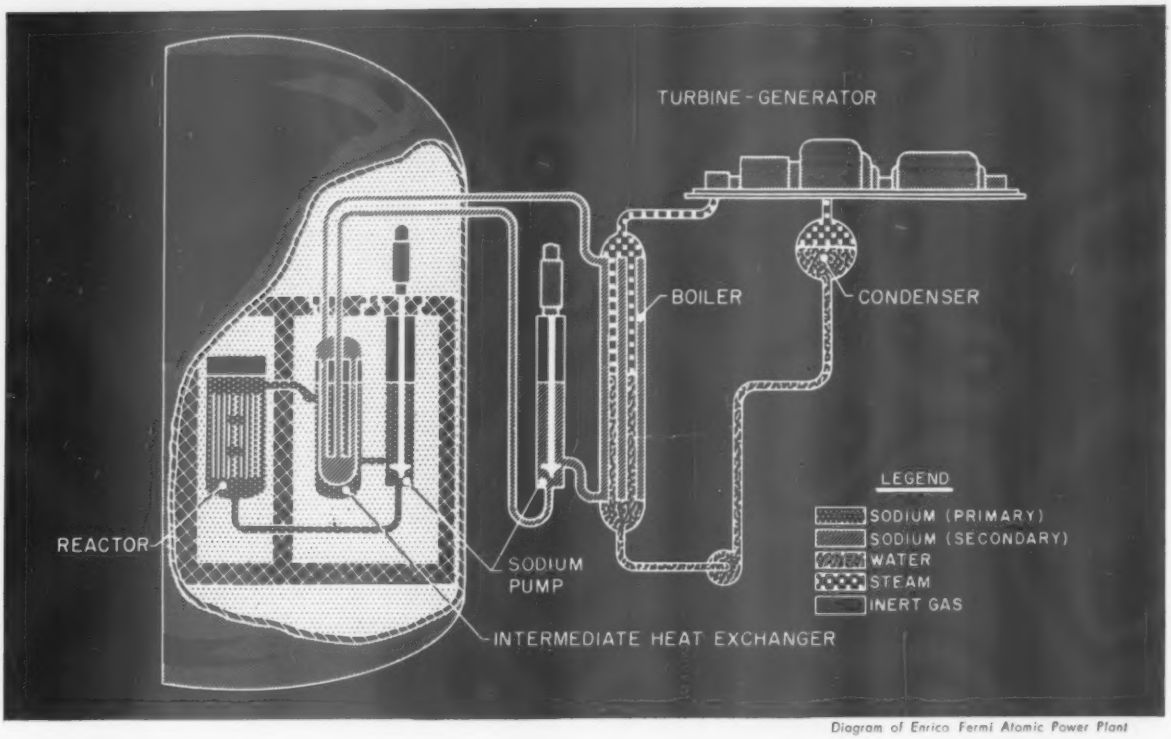

Diagram of Enrico Fermi Atomic Power Plant

SODIUM-COOLED FERMI REACTOR WILL GIVE FAST BREEDER DESIGN FIRST FULL-SCALE PLANT TEST

Enrico Fermi Reactor, now under construction on Lake Erie near Monroe, Michigan, is the first large-scale power plant of its type, will demonstrate feasibility of fast breeders for electric power production.

The fundamental advantage inherent in fast breeder reactors is that they produce more nuclear fuel than they consume. Consequently, this type of reactor will conserve and add to the nation's reserves of nuclear fuels rather than deplete those resources.

The Fermi Reactor, now being built by Power Reactor Development Co. (PRDC), is scheduled to go critical late next year. It is designed to generate 300,000 thermal KW, which will be converted to 100,000 electrical KW through a conventional steam cycle. Detroit Edison will build and own the steam turbine-generator, which it will operate on steam purchased from PRDC.

Liquid metallic sodium will transfer the heat generated in a tandem heat-exchange system. In the primary loop, sodium will enter the reactor at 550°F, leave it at 800°F. This heat will be transferred to secondary loops which will enter the steam generator at 750°F, leave it at 500°F. Steam will be produced at 740°F and 600 psia.

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- Sodium Reactor Experiment (SRE) Santa Susana, Calif. — graphite-moderated—6,500 KW (e) (operational)
- Experimental Breeder Reactor-2 (EBR-2) NRTS, Arco, Idaho—fast breeder—20,000 KW (e) (under construction — slated for 1960 operation)
- Consumers Public Power District, Hallam, Neb.—graphite-moderated —75,000 KW (e) (under construction—slated for 1962 operation)
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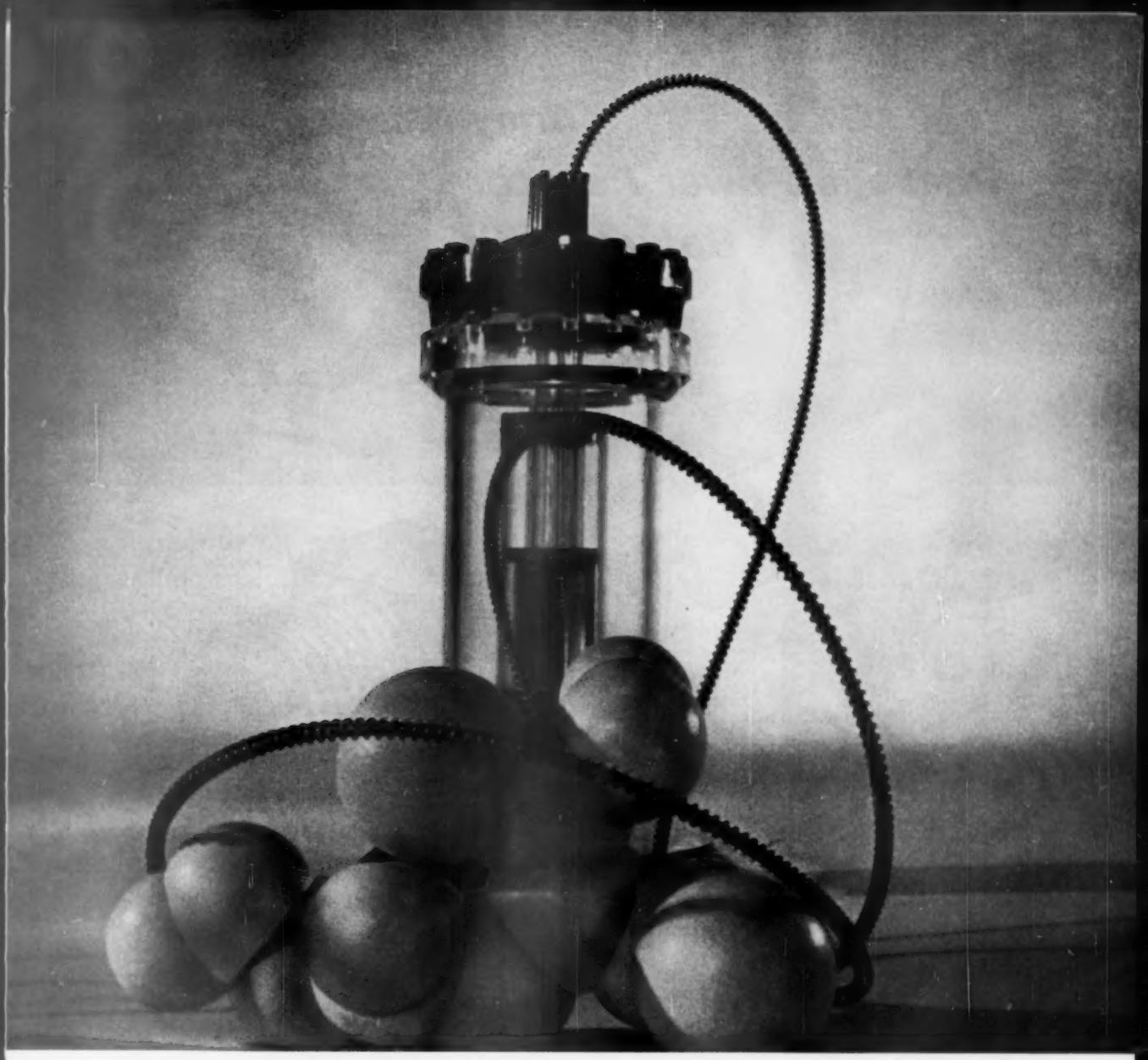

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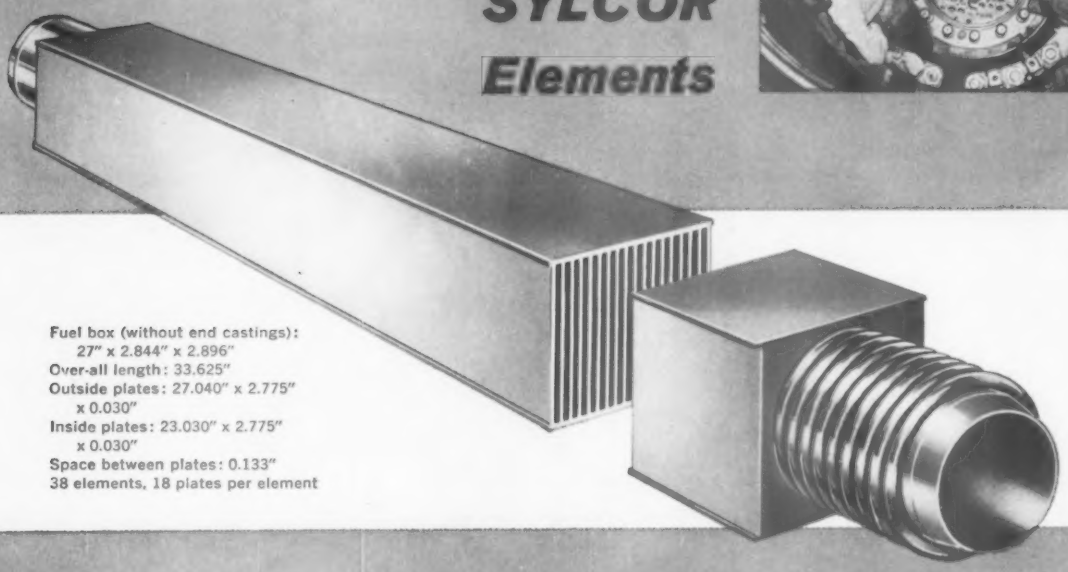
Army Package Power Reactor Refuels with SYLCOR Elements



Fuel box (without end castings):
27" x 2.844" x 2.896"
Over-all length: 33.625"
Outside plates: 27.040" x 2.775" x 0.030"
Inside plates: 23.030" x 2.775" x 0.030"
Space between plates: 0.133"
38 elements, 18 plates per element

SM-1 is a prototype of reactors designed for use in remote locations where it is difficult and costly to supply coal and oil. It is notable among low-power reactors because complete reliability in operation must prevail with minimum maintenance facilities. New fueling is planned for late 1959 and SYLCOR is under contract to ALCO Products, Inc., builder and operator of the plant, to make the fuel elements... the first award to a commercial firm for the fueling of an Armed Forces "Package Power" reactor.

Unique technological and production skills permit SYLCOR to meet the contractor's rigid specifications concerning water-gap spacings, surface characteristics, construction and assembly.

The SYLCOR fuel elements will consist of 18 plates of UO_2-stainless steel core clad in stainless steel, and are among the first to incorporate a dispersed burnable poison (Boron Carbide).

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Write also for "Nuclear Fuels: Key to Reactor Performance" and "Physical and Engineering Properties of Materials for Nuclear Fuel Elements." Sylvania-Corning Nuclear Corporation, Bayside, Long Island, New York.

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Measuring Large Radiation Doses

Irradiation technology is developing fast. New designs for irradiators, irradiation reactors (the new word for them is "chemonuclear") and electron accelerators are on the drawing boards. Accelerator and radionuclide sources are already on line, sterilizing sutures and making membranes and wire insulation. Other large-volume radiation uses are balanced on the edge of economic margin, ready to fall into the market place when radiation is a little cheaper or required doses are a little smaller.

Essential to this growth is the study of radiation dosimetry. The subject of dosimetry is an old one, but in the past it has been limited mainly to personnel monitoring for safety (0–100 mr) and measurements for radiation therapy (100–50,000 r). As accelerator beams turn from living substances to engineering materials, dosimetry problems change. Doses are likely to be 100,000 times the ones that interest biologists. Dose rates are similarly larger. Readout must be quick and simple to meet the demands of commercial competition. Automatic systems must replace tedious plotting and computing.

Differences of requirement create a chasm between the solid foundation of biological dosimetry and the growing structure of materials dosimetry.

This report has been planned and prepared as a survey of current work on measuring large radiation doses. We asked the experts which systems are most promising. We asked them for the characteristics of these systems (see table on pages 70 and 71). We asked several of them to review the kinds of systems that appear to have the most promise. From their references we have gathered a large bibliography of important publications in large-dose dosimetry (pages 75 and 76).

We have deferred neutron dosimetry to a later time. Sometimes the purpose of neutron dosimeters is the same as those for fast electrons and photons. However, the methods are quite different. Thus the present report is limited to electron and photon dosimetry.

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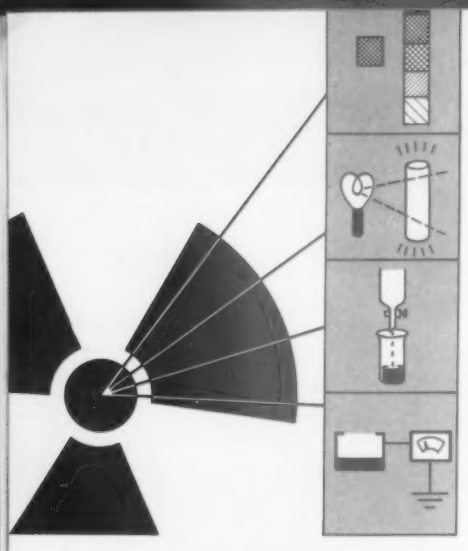


Glass Dosimetry

By NORBERT J. KREIDL and GERALD E. BLAIR
Bausch & Lomb Optical Company, Rochester, New York

MOST GLASSES undergo changes in easily measurable properties as a result of irradiation. Optical-absorption and luminescence changes are most applicable to dosimetry.

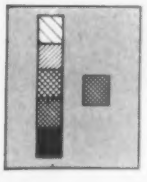
The advantages of glass as a dosimeter material include ruggedness, shelf-life stability, stability of radiation-induced changes, reproducibility, low cost and capability of being manufactured in practically unlimited size and shape. The dose range covered by existing systems is from 1 rad to 5×10^6 rads. These systems are nonabsolute and require calibration against some primary standard, such as a carbon calorimeter (*Ha₄58*).

The absorption change in silver-activated phosphate glass (*Da₁56, Sc₂55*) is very useful in the dose range from 10^3 rads to 3×10^5 rads. In this range, a linear relation is found between dose and change in absorption. Above this range, a saturation effect limits its usefulness. Also, the stability of the induced absorption band is poor at the higher dose range. This fading effect can be tabulated but is a problem with widely varying dose rates.

A study of the mechanism of coloration of glass showed that transition ions, of electronic structure similar to cerium, prevent the normal "browning" in optical glasses (*Kr55*). However, in preventing the visible bands from forming, new stable absorption bands were formed in the near-ultraviolet region of the spectrum. Glasses were developed based on these researches with properties desirable in a high-level dosimeter (*Kr56a, Kr56b*). In particular, a borosilicate glass (F-0621) was developed that shows linearity of response up to 10^6 rads with high sensitivity and good stability of the new absorption bands formed. Although the changes in absorption with dose is nonlinear above 10^6 rads, the useful range can be extended to at least 5×10^6 rads. In studies done under contract to the Quartermaster Food & Container Institute (*Ta₁58*), this system was found to have a precision of $\pm 2\%$, dose-rate independence up to at least 10^6 rads/sec and postirradiation stability of 1–2% (dependent on dose and measuring wavelength). As a result of this and additional work at the National Bureau of Standards (*Ha₄58*), the Quartermaster Corps is considering this glass as a secondary standard for its food-irradiation program.

One of the first uses of a luminescent change in glass for dosimetry was the DT-60/PD personnel dosimeter of the U. S. Navy (*Sc₂53b*). The sensitive element is a small square of silver-activated phosphate glass. This glass develops an ultraviolet-excited orange fluorescence proportional to dose. A miniaturized application was developed for this glass (*Bl₂59, Sc₂53a*). A small cylinder of the glass (1 mm × 6 mm) measures dosage in the range 1–10,000 rads. The fluorescent center formed with irradiation is very stable and is not altered by the ultraviolet excitation necessary for reading.

Thermoluminescence has been reported in samples of fused silica exposed to high doses of gamma irradiation in a study of the synthesis of color centers (*He₃59*). The amount of thermoluminescence was highest in undoped samples and was partially quenched by the addition of small amounts of foreign cations. Thermoluminescence might be applicable to glass dosimetry.



Photographic Methods

By H. F. NITKA, *Ansco Research Laboratories, Binghamton, New York*

PHOTOGRAPHIC FILM is the oldest radiation detector for determining total radiation dose. However, because of its sensitivity, ordinary photographic film has been confined mainly to the measurement of small doses, as in monitoring for personnel protection. For instance, an ordinary black-and-white film having an ASA exposure index of 100–200 yields a silver density, after processing, of approximately 0.5 for a dose of only 1 r (*Co₂55*). Photographic high-level dosimetry (10^4–10^8 r) has been made possible by the photographic print-out effect, i.e., the photolytic reduction of silver without development (*Dy54, Ni₂57*). The advantages of print-out dosimetry are simplicity, nondirectional response, no need for processing, instantaneous indication of the integral dose received and extremely low costs.

Photographic print-out emulsions do not require wet processing, i.e., developing and fixing, as do standard photographic negative and positive emulsions. A print-out emulsion contains excess silver ions, which deposit on the sites where silver ions were reduced to silver by light absorption. In a normal photographic emulsion, there are no excess silver ions. Silver is reduced and deposited by the catalytic reaction of the developer from the silver-halide crystal at the latent-image specks that are formed by light absorption. This

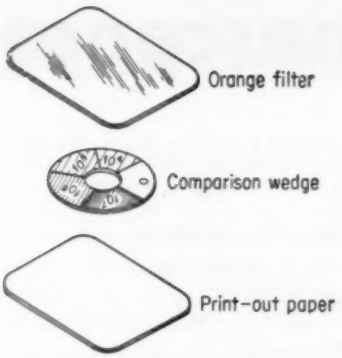


FIG. 1. PHOTOGRAPHIC DOSIMETER using print-out paper; print-out emulsion is partly covered by density-comparison wedge and enclosed in orange-dyed gelatin or cellulose-triacetate light filter for protection against actinic light. Comparison wedge is opaque gray scale printed on paper; dosimeter density is compared around wedge and through center hole

reaction with the developer represents an enormous amplification factor ($>10^9$), thus explaining the "faster speed" of normal emulsions as compared with print-out emulsions.

High-Energy Response

The sensitivity of any photographic emulsion is constant for energies higher than 0.6 Mev (*Gr51*). Below 0.6 Mev, the response of any photographic emulsion increases with decreasing radiation energy, and, therefore, a separate calibration for each energy is needed.

Photographic emulsions used with standard processing techniques possess a rate-independent response to high-energy radiation. This appears to hold also for the print-out effect of commercial X-ray emulsions,* whereas special print-out emulsions exhibit a slight rate dependence (*$Ni_2$57*) as discussed in the following section.

Special Emulsions

The response of a special, high-speed print-out emulsion (*Dy54, $Ni_2$57*) coated on paper or a transparent film base to a Co^{60} source has been shown to cover a range of 50,000 to several million roentgens. This range can be readily increased by a factor of 50–100 either by the use of ordinary commercial print-out emulsions instead of the special high-speed emulsion or by adding a 3-in.-thick lead filter. The latter attenuates gamma radiation in the 1–3-Mev energy range by a factor of 50.

The response of print-out dosimeters using such an emulsion depends somewhat on the dose rate, at least over the range 10–10^4 r/min. Higher rates have not been checked so far, but no significant change is expected up to rates of 10^5 r/min as might be used in food preservation.

The optical density of the print-out silver is determined either visually by comparison with an adjacent density step tablet calibrated in roentgens (accuracy ±30%) or by means of densitometers (accuracy ±5%).

The design of a print-out dosimeter badge is shown in Fig. 1. Units of this type can be made into a perforated ribbon.

Commercial X-Ray Film

Ordinary commercial X-ray film can also be used for high-level dosimetry.* Photolytic print-out silver is formed on these films by gamma-ray exposures in the range 10^4–10^8 r.

Different emulsions exhibit slight differences in the color of the print-out silver. For this reason, the density is measured through narrow-band-pass filters corresponding in their transmission to the spectral absorption maximum of the photolytic silver. In Fig. 2, the net transmission density is shown for various exposure rates and doses from a Co^{60} source.

By measuring the density on three superposed pieces of identically exposed films, the precision of reading for exposures below 10^6 r can be improved to ±5%. It might be mentioned that the films become quite brittle for exposures extending beyond 5×10^7 r.

No rate dependence for Co^{60} exposure over the dose range 2×10^2–5×10^5 r/hr is observed. The energy dependence is similar to that of the special print-out emulsion and that of chemically developed emulsions; i.e., a separate calibration is required for radiation energies below 0.6 Mev. Inasmuch as the photographic print-out process is based on the ionic mobility of silver ions, the formation of photolytic silver depends on the temperature. Therefore, it is advisable to keep the temperature constant for greater accuracy, say within ±10° C from the calibration temperature if an accuracy of better than ±10% is desired.

For dosimetric purposes, it is recommended to protect the film badges against moisture by water-tight envelopes.

In most practical cases, the energy and rate of the applied radiation are known, and all that is required is a calibration of the dosimeter under the chosen conditions.

* W. L. McLaughlin, National Bureau of Standards, to be published.

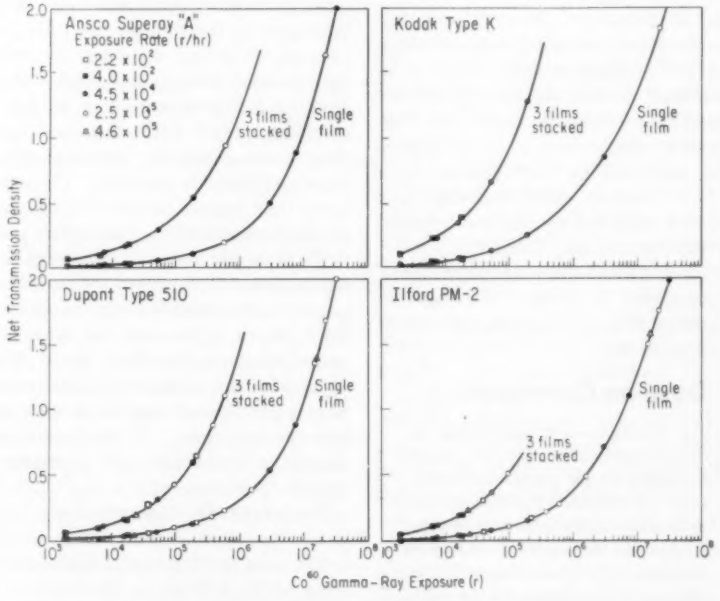
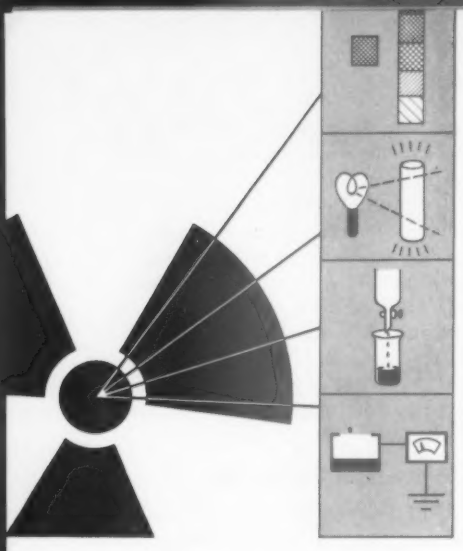


FIG. 2. COMMERCIAL X-RAY FILM transmission densities for various exposure rates and doses from Co^{60} source



Luminescence

By FRANK H. ATTIX, *U. S. Naval Research Laboratory, Washington, D. C.*

AMONG THE MOST promising systems for measuring large radiation doses is luminescence degradation.

Many organic luminophors show decrease in luminescence with exposure to high-energy radiation. To use the effect as a dosimeter one observes the post-irradiation luminescence at a frequency in the visible or near-ultraviolet spectrum in response to a higher-energy excitation (Table 1). The system we have been developing uses wafers of anthracene and *p*-quaterphenyl and offers the following advantage for dosimetry:

- Adequate sensitivity over a range of 5×10^5–5×10^9 rads
- Ease, simplicity and rapidity of measurement
- Accuracy of $\pm 10\%$ or better
- Dose-rate independence
- Good match, in atomic number, to plastics, oils and rubbers
- Small size

There are also some disadvantages, of which one is inherent and two are capable of improvement. These are:

- Nonlinear response
- Some instability in time
- Some inconvenience in packaging

Another luminescence-degradation dosimeter uses small concentrations (10^{-5}–10^{-8} mole/liter) of quinine in water (*Ba58*). X-ray doses from 5 rads to 2×10^4 rads cause an exponential decrease in ultraviolet-excited luminescence. Dependence on dose and initial concentration can probably be explained in terms of radicals created by radiation damage to water. The system looks promising in the range of the ferrous-ferric dosimeter and for lower doses.

Scintillation efficiencies of crystal, plastic and liquid scintillators decrease and hold promise as dosimetry effects. One system that has been studied is diphenyloxazole (PPO) in xylene excited by curium alpha particles (*Be$_2$58*). Plastic scintillators show a degradation that is independent of dose rate but dependent on the nature of the radiation—that is, on linear energy transfer (*Ro$_3$57*). Plastics studied include pure polystyrene, polystyrene with 1.5% 1:1:4:4-tetraphenylbutadiene (TPB) and polystyrene with 3% *p*-terphenyl and 0.02% TPB.

Dosimeter Design

The author has extended the development work of Schulman to produce a workable system for large-dose dosimetry (*At59*, *Sc$_2$57*). Penny-sized wafers of anthracene and *p*-quaterphenyl are excited at 3,650 A and read through a filter with a pass band centered at 4,420 A. Contrary to previous reports (*Sc$_2$57*, *Bi50b*, *Bi51*) there is some recovery of luminescence. Heat treatment (1 hr, 100° C) accelerates it and stabilizes readings for at least a month.

The development work that led to this system used powdered anthracene and naphthalene. Powders were felt to offer lower cost and better reproducibility than single crystals. They were irradiated in vials and packed into depressions in Bakelite plaques for fluorescence measurements. Degradation was produced by Co^{60} gamma rays, 2-Mev electrons, 50-kvp X-rays and 3,650-A ultraviolet. Similar behavior is observed for all (Table 1).

There was no dose-rate dependence. Irradiations in helium and vacuum produced the same degradation as irradiations in air.

Dose on Conveyors

For conveyor-belt operations luminescence-degradation would provide a simple system for dosimetry. A solution of anthracene in an organic solvent such as chloroform can be painted on each package. Its fluorescence under ultra-violet excitation as the package leaves the irradiator will give an automatic reading of dose.

Future Development

There are still improvements to be made in the present system. Here are several areas that deserve further investigation:

Recovery. This may cause difficulty in very long exposures (~1 month) in spite of the post-irradiation heat treatment. Other materials may ultimately prove to be better than anthracene or *p*-quaterphenyl in this respect. Purity could be a factor in the recovery.

Packaging. It may be an improvement over the pressed-wafer method to support the luminescent material in a thin layer on a rigid backing such as polystyrene. Exploratory work toward this kind of support has been done by Taimuty. The technique should be re-examined. In the case of *p*-quaterphenyl the raw-material cost (~$2/gm) could be greatly reduced if this technique were successful. If this approach does not prove workable, the pressed-wafer diameter can be reduced at least by half without loss of accuracy. Thus the cost of a quaterphenyl wafer would be less than 20 cents.

Adjustment of response. An effect analogous to the Bragg-Gray principle of cavity ionization chambers can probably be used to make a dosimeter that responds in the same manner as irradiated samples. Ultraviolet-excited fluorescence originates within about a micron of the wafer surface. This suggests that response can be made dependent upon the flux of secondary particles from any material placed against the surface. A thin layer of the luminophor can be sandwiched between two thick layers of the material in which one is measuring absorbed dose. Hydrogenous and nonhydrogenous materials might be used together to indicate fast-neutron dose. Nonhydrogenous materials would produce a response mainly to gamma rays.

Temperature dependence. The work reported to date has been carried out at room temperature. Preliminary work by C. S. Sharn at this laboratory shows that no difficulties are encountered up to at least 50° C.

Degradation

Degradation of plastic scintillators. The very high dose range covered by polystyrene-base plastic scintillators (*Ro₃57*) suggests that further investigation is worthwhile. Acitelli and his coworkers are currently engaged in such work at Bausch and Lomb.

How Does It Work?

An "exciton" theory successfully explains luminescence degradation as the result of introduction of impurities by radiation damage (*Bi50a, Bi50b, Bi51, Bo₂49*). In a small anthracene crystal irradiated and excited with alpha particles, there is no change in the number of scintillations, but the scintillation amplitude gradually decreases. No recovery was reported over a two-week period. Optical absorption accounts for only a small part of the decrease.

A simple equation describes the decrease in scintillation efficiency. The same equation has been found to apply to many other scintillators and luminophors and can be written in terms of either the number of particles per square centimeter or the absorbed dose. It is

$$I/I_0 = 1/(1 + NA) = 1/(1 + D/E_{½}) \quad (1)$$

(I = pulse amplitude or luminescence intensity; I_0 = original value of I; N = number of incident alpha particles per square centimeter; A = damage coefficient (cm²/alpha particle); D = absorbed dose; $E_{½}$ = dose required to reduce pulse amplitude or luminescence to half of original)

Table 1 shows the degradation characteristics of various scintillators and luminophors, including A and $E_{½}$.

In solid form and before heating, all organic luminophors except *p*-quaterphenyl appear to follow Eq. 1. Other systems show somewhat different responses. For example, if organic luminophors are incorporated in polystyrene, the intensity of their fluorescence under electron-beam excitation follows this equation (*Hi₂54*):

$$\frac{I - I'}{I_0 - I'} = \epsilon^{-\alpha N} \quad (2)$$

(I = fluorescence intensity; I_0 = initial fluorescence intensity; I' = a minimum value of I' after prolonged irradiation; α = degradation constant; N = exposure in electrons/cm²)

Values of α range from 1.7×10^{-15} cm²/electron for hydroquinone-dicarboxyl-diethylester to 15.7×10^{-15} cm²/electron for 1,4-dioxyanthraquinone, both in concentration of 1% in polystyrene. Values of α are strongly dependent on concentration, increasing rapidly at low concentrations.

Degradation of crystalline hydroquinone-dicarboxyl-diethylester follows Eq. 1 rather than Eq. 2. Thus dissolving the luminophor in polystyrene definitely changes its degradation.

Luminescence damage in other plastic scintillators (*Ro₃57*) follows no simple form. The initial parts of the curves show an $\epsilon^{-\alpha N}$ dependence.

Dose-rate dependence has been reported only once (*Wr₁53*).

TABLE 1—Degradation in Scintillators and Luminophors

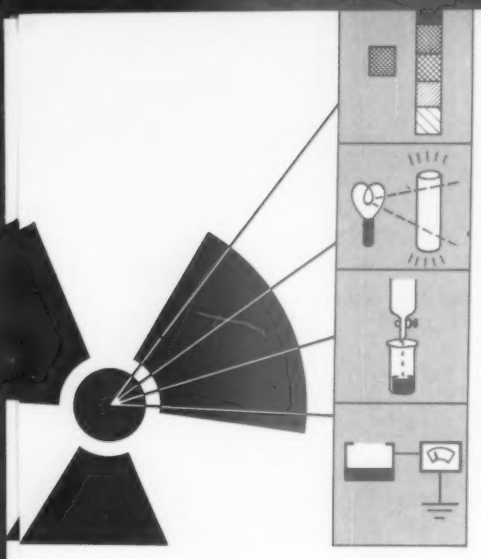
Material	Reference	Degradation parameters: A* (10^{-11} cm²/particle)	$E_{½}$* (erg/cm²)	$E_{½}$* (rad)	Damaged by	Excited by
Anthracene	*Bi50a*	1	2.6×10^8	2×10^8	Po^{210} α's	Po^{210} α's
"	*Bl₁53*	2	1.3×10^8	1×10^8	"	"
"	*Wr₁53*	4.8	5.4×10^7	4.2×10^8	"	"
"	*Ha₂57*	4.0	6.5×10^7	5.2×10^8	"	"
"	*Sc₂57*	—	—	1.1×10^6	Co^{60}	3650-A UV
"†	*At59*	—	—	6.0×10^5	"	"
"‡	"	—	—	1.1×10^6	"	"
"	*Bl₁53*	—	$\sim 8 \times 10^{11}$	6×10^5	3650-A UV	"
"§	"	—	1.5×10^8	1.2×10^8	S^{35} β's	S^{35} β's or Po^{210} α's
Naphthalene	"	1.5	1.7×10^8	1.5×10^6	Po^{210}	Po^{210} α's
"	*Sc₂57*	—	—	6.6×10^5	Co^{60}	2537-A UV
Terphenyl	*Bl₁53*	47	5.5×10^8	4.5×10^6	Po^{210} α's	Po^{210} α's
Stilbene	"	37	7.0×10^8	6.0×10^6	"	"
"	"	—	$<4 \times 10^{10}$	$<3 \times 10^8$	3650-A UV	"
Pyrene	"	~20	1.3×10^9	—	Po^{210} α's	"
Diphenyl acetylene	"	800	3.2×10^9	—	"	"
p-Quaterphenyl†	*At59*	—	—	4.0×10^7	Co^{60} and 2-Mev electrons	3650-A UV
"‡	"	—	—	5.6×10^7	"	"
Polystyrene	*Ro₂57*	—	5×10^9	5×10^7	Po^{210} α's	Po^{210} α's
Polystyrene + 3% PT + .02% PTB	"	—	6×10^9	6×10^7	Po^{210} α's	Po^{210} α's
Polystyrene + 1.5% PTB	"	—	9×10^9	8×10^7	"	"
Polystyrene + 1.5% PTB	"	—	1.7×10^{10}	1.6×10^8	Ce^{144}–Pr^{141} β's	Ce^{144}–Pr^{144} β's

* For significance of A and $E_{½}$ see equation in text. † Before heating. ‡ After heating. § No degradation observed. (References are to bibliography, pp. 75, 76.)

Theory

The exciton theory assumes that radiation damage introduces impurities (*Bo₂49, Bi50a*). In an undamaged crystal, excitation energy originally imparted by radiation is transferred by resonance from molecule to molecule until one molecule fluoresces instead of handing the exciton along. However, a travelling exciton can be caught by an impurity and degraded to heat or to a wavelength outside of the fluorescence band of the pure material.

The observed degradation implies a long range for the excitons (*Ha₂57, Ro₂59*). Recent investigation concludes one must assume a constant probability that excitation of any molecule in a crystal will result in quenching regardless of the distance of the excitation from a quenching molecule. Lower limit of exciton range is 1,000 A, corresponding to 3×10^4 jumps of energy from molecule to molecule.



Plastics Dosimetry

By CHARLES ARTANDI, *Ethicon, Inc., Somerville, N. J.*

PLASTICS EXHIBIT several types of changes on irradiation. Most changes depend only on total dose. Some are dose-rate dependent because of the influence of dose rate on free-radical concentration. Some changes are of high-enough order to serve as measures of radiation dose.

Radiation-induced changes have their origin in the rupture of covalent bonds in organic molecules. Effects are small in simple organic compounds, but they are much more pronounced in polymers. For example, one crosslink per mole makes a linear polymer into three-dimensional network with vastly changed physical properties (*Ch*$_3$*58*).

Changes Available

Among radiation-induced changes in plastics are those in appearance, chemical state, physical state, and mechanical properties. Appearance changes with temporary and permanent color effects and bubbling. Chemical changes include double-bond formation, dehydrochlorination, crosslinking, oxidative degradation, polymerization, depolymerization and gas evolution.

Physical changes include effects on viscosity, solubility, conductivity, free-radical spectra, fluorescence and crystallinity. Changes in crystallinity are indicated by measurements of density, heat of fusion, X-ray diffraction and other properties.

Mechanical properties that change are tensile strength, elastic modulus, hardness, elongation, flexibility, etc. When cross linking occurs in linear polymers it hinders uncoiling and slippage. This leads to increased elastic modulus, decrease in plastic flow and decrease in elongation (*Ry53b*).

While all of these types of changes have potential value for dosimetry, no one so far has developed a system depending only on physical or mechanical changes. Several systems use color changes and other kinds of chemical changes.

Color Changes

Ionizing radiation causes coloration in many plastics. The underlying chemical and physical changes are little known, but several theories are advanced. According to some the color is due to electron or free-radical trapping similar to that of ionic crystals. The fact that the coloration is irreversible in most cases appears to contradict this.

When polyvinylchloride (PVC) is exposed to ionizing radiation, the primary process is probably dehydrochlorination with the formation of a double bond. The chlorine next to the double bond becomes allylic, very mobile, and easily removed.

It is conceivable that successive dehydrochlorinations are spontaneous and no new irradiation is required. This would explain the intensification of color by heat (*Ch*$_2$*56b*). The end result is formation of a conjugated-double-bond system. This would account for the reddish color.

The processes are similar to those obtained by base-accelerated degradation of PVC (*Ca*$_1$*55*), or thermal decomposition in vacuum (*St*$_2$*58*). Aging or irradiation by ultraviolet light also produces color, indicating that the radiochemical, photochemical and thermal effects are the same as those initiated by radiation.

Oxygen plays an important role in the degradation process by using up free radicals or attacking double bonds and causing cleavage of the main chain. In vacuum and inside the solid, crosslinking is predominant. Free radicals combine with double bonds forming new radicals that can chain-react and regenerate the original radicals. If the chain length is short, this reaction is more probable. It is conceivable that the concentrations of free radicals and double bonds have to be built up sufficiently before crosslinking can occur. In fact crosslinking is observed only at high doses.

PVC turns green first, then yellow, amber, reddish-brown depending on the dose. The color reaches a maximum in 3–4 days at room temperature. There are several absorption maxima, the one at 3,960 A being most sensitive. Exposure to elevated temperature accelerates the development of color up to a point. At 80–85° C the maximum intensity can be obtained in 5–10 min. At 50° C several hours are required. Above 85° C the color for the same exposure becomes less and less intense for increasing temperatures. This phenomenon may be explained by the elimination of some of the chromofor (polyenic) groupings through crosslinking or some other chemical reaction. It has been shown that PVC irradiated at room temperature exhibits additional crosslinking when kept at 90–100° C (*Ch*$_3$*58*).

Coloration of PVC by radiation is proportional to absorbed dose. Therefore the system can be used for dosimetry in the range of 10^5–10^7 rads (*Ar*$_2$*58*). The presence of aromatic plasticizer influences the coloration through absorbing most of the energy in vibrations. The presence of stabilizers, pigments or dyes will also change the color response. Rigid PVC of standard quality gives reliable and reproducible results.

In polymethyl methacrylate (Lucite, Plexiglas) radiation causes changes in both color and ultraviolet absorption. We have found neither effect usable for dosimetry. Two visible colors appear: (a) yellow, which persists even after prolonged heating at 80° C and (b) reddish, which fades—particularly at 80° C.

The increase in ultraviolet absorption is probably caused by formation of double bonds (*Ch*$_2$*56a*). We have attempted to use this effect for dosimetry, but in the range $1–6 \times 10^6$ rads nonlinearity limits its usefulness.

Polyethylene terephthalate shows increased absorption at 3,250 A as the result of irradiation. The color rapidly fades in the first 24 hr. With very

thin films the range can be extended up to 2×10^8 rads (*Bo₁58*).

Chemical Changes

There is no general theory that predicts or even explains the behavior of all polymers under irradiation. Polymers are characterized as degrading or crosslinking. Those with alpha hydrogens favor crosslinking while the ones with alpha methyl groups favor cleavage. Unfortunately there are exceptions in both classes.

It is thought that the stability of radicals formed is an important factor (*Wa54*). Steric hindrance may also play an important role. Polymers with internal rearrangement leading to main-chain rupture degrade, but if there is no ready configuration by which the radical or activated molecule can rearrange, it will crosslink (*Al54*).

Polymerization. Acetylene irradiated by ionizing radiation polymerizes to cuprene and benzene at a rate dependent only on the rate of absorption of energy. Cuprene is the predominant product [G(acetylene) = -71.9, G(benzene) = 5.1]. These rates are independent of acetylene pressure and radiation intensity.

For dosimetry in irradiation of vapors and gases, the change in acetylene pressure is measured and corrected for benzene (*Do55*, *La₂57*).

A visual-indicating dosimeter is based on polymerization of acrylonitrile. Polyacrylonitrile is insoluble in its monomer. Turbidity occurs at doses that depend on dose rate (*Bc₃53*).

Aqueous solution of acrylonitrile can also be used for dosimetry. The solution is deaerated and sealed into a dilatometer. Contraction is read by a microscope, and it relates to the weight of polymer formed (*Co₁52*).

Acrylonitrile, vinylacetate, methylmethacrylate or styrene monomers sealed in a dilatometer can serve as dosimeters. The sensitivity varies with the monomer (rate of polymerization) and with the diameter of the capillary. Precision depends on the purity of the particular monomer used (*Pr₁50*).

Degradations. A dosimeter that uses degradation has polystyrene in carbon tetrachloride solution sealed in a flow-type viscometer. On irradiation the number of bonds cleaved in a polymer solution is independent of both the molecular weight of the polymer and polymer concentration but increases linearly with dose. The log-log plot of a flow time function against a dose function is a straight line over a wide range (*Fe58*).

The very high free-radical yield of carbon tetrachloride is instrumental in the breakdown of polystyrene. The numbers of free radicals produced per 100 ev are: styrene, 1.6; carbon tetrachloride, 70.

Dosimetry is also possible by irradiation of polymethyl methacrylate in solid state. For each main-chain cleavage approximately one ester side chain is decomposed. Viscosity change is the measure of dose. The plot of the reciprocal of viscosity molecular weight versus dose gives a straight line, and the relationship is maintained over a hundredfold change in molecular weight (*Al54*).*

Gas evolution. Various processes result in gas evolution. The most commonly evolved gas is hydrogen, which is associated with free-radical or double-bond formation and crosslinking. Methane, ethane and other homologs occur as reaction products of various radicals with hydrogen atoms. CO and CO_2 accompany hydrogen in the decomposition of side chains of irradiated polymethyl methacrylate.

Halogenated polymers exhibit dehydrochlorination with simultaneous double-bond formation or evolution of halogens or halogenated hydrocarbons (combination of a free radical with halogen atom). Halogenated plastics are more applicable for the purpose of dosimetry because acids and halogens are easier to measure quantitatively than gases.

Although the gas formation is instantaneous, the evolution from solid plastics is slow because of the rigid structure and the slow diffusion.

Two difficulties are encountered: (a) slow diffusion, making measurements lengthy and (b) dependence of rate of evolution on sample size and shape.

Polytetrafluoroethylene irradiated under NaOH solution shows evolution of fluorine. Log of dose plotted against log of fluorine liberated per gram of plastic gives a straight line (*Ry53a*). According to some there is no definite evidence that fluorine is liberated (*Ch₂52*). The carbon-to-carbon bonds fracture preferentially because their bonding energy is lower than that of carbon to fluorine.

An elegant method uses dehydrochlorination of polyvinylchloride (*He₂51*). It incorporates an acid-base indicator dye in the plastic film and measures the color change after irradiation with a spectrophotometer.

* R. Dowd et al, unpublished work, Ethicon Research Division.

Microbial Monitors

By VELMA L. CHANDLER, *Ethicon, Inc., Somerville, N. J.*

IN RADIATION STERILIZATION the most direct method of dosimetry is microbial monitoring. A harmless microorganism is irradiated with the product. After irradiation the number of survivors capable of reproduction serves as a measure of dose. If one selects a microbial monitor that has the same radiation resistance as the organisms that are to be killed in sterilization, total killing of the monitor indicates sterilization of the product. As indicators of various sterilization processes, microbial monitors are superior to chemical, physical or electrical ones.

There is a linear relationship between density of microorganisms and radiation dose required to sterilize (*Ch₁59*). Thus the number of spores used for monitoring must be chosen with judicious care. A guide is to use a contamination level slightly greater than what might be normally anticipated in the natural product.

Techniques

In one microbial-monitoring system a dry organism is put on plastic film to which it adheres (*Ma59*). After irradiation the organism is cultured on agar-

TABLE 1—Resistances of Bacterial Spores*

Spore system†		*Highest dose showing all positive cultures (10^6 rads)*	*Lowest dose showing all negative cultures (10^6 rads)*
E-3	Clostridium tetani	1.3	1.8
E-601	Bacillus species	1.0	1.6
E-594C	Bacillus species	0.8	1.6
E-58	Clostridium sporogenes	1.1	1.4
E-2	Bacillus subtilis	1.1	1.3
E-44	Clostridium sporogenes	0.8	1.2
E-599	Bacillus species	0.8	1.2
E-606	Bacillus species	0.8	1.1
E-627	Bacillus species	0.7	1.0
E-533A	Bacillus coagulans	0.4	0.8
E-626	Bacillus species	0.3	0.5

* Original table reported in *megareps* (*Pe₁56*).
† To each disk was applied 0.1 ml of a suspension containing 5×10^5 organisms per ml.

gel plaques. If no colonies appear, the result indicates sterilization. Alternatively one can place a representative sample on a microscope slide and count the number of viable survivors.

The author and her colleagues use a spore suspension in water (*Pe₁56*). A drop is placed on a 1-cm-diameter disk of filter paper. This is either dried before irradiation or sealed in a polyethylene envelope and irradiated wet.

A new tool developed in our laboratories provides a standard technique for conducting electron-beam dosimetry studies with any type of microorganism (*Ch₁59*). It is an aluminum step wedge under which an array of impregnated disks is irradiated. It is designed to produce a dose range to the disks of 0.2–2.5 million rads in one exposure. Using a two-dimensional array of disks permits us to vary both dose and original concentration.

Survival Curves

Unfortunately, existing microbiologic literature on radiation studies usually stresses the types of survival curves obtained after irradiation of microorganisms. Thus emphasis is on *mean lethal dose* (inactivation dose or 37% dose) first proposed by Lea (*Le₁55*). However, legal requirements for sterile products produced and sold in this country demand that microbiologic tests (as provided by the current edition of the Pharmacopeia of the United States) show the complete absence of viable microorganisms. Thus pharmaceutical suppliers are interested in *absolute* lethal doses.

Radiation Resistance

It has long been known that among the bacteria and fungi, bacterial spores are the most resistant to actions of temperature and chemicals. It is not surprising that they also are the most resistant to radiation (*Be₁54, Br₁56, Ko₂56, Pe₁56*). There are marked differences in radiation resistance among the various species of sporeforming bacteria, the *Bacillus* and *Clostridia* genera (*Be₁55, Pe₁56*). Table 1 depicts the range of electron-beam doses required to destroy a variety of bacterial spores. It is generally agreed that $1.7–1.8 \times 10^6$ rads will destroy the growth and reproduction abilities of bacterial spores in concentrations of $10^3–10^4$ per ml provided they are not protected by extraneous dense substances. It has been found that species of bacterial spores highly resistant to heat or chemicals are not necessarily the most resistant to radiation.

Recent techniques developed in our laboratories by W. Koh and J. Olivo confirm the data of Table 1. They use 5-Mev electrons to irradiate filter-paper disks that are impregnated, sealed in polyethylene bags and sandwiched between layers of cardboard to get a range of doses. A similar study has determined the depth of polyethylene bags through which sterility can be effected. *B. thermoalimentophilus* served as the monitor (*Ma59*).

Dosimetry studies conducted over four years with different spore suspensions of the same parent strains of *Bacillus pumilus* and *Clostridium tetani* have shown that their sensitivities to electrons from a Van de Graaff accelerator and a microwave linear accelerator have not changed.

Which Species?

Bacterial spores for monitoring pharmaceuticals and foods must have large radiation resistance. In addition the normal, natural microflora associated with a given product should be studied and those types that appear to show radiation resistance should be more thoroughly investigated. It is always possible that some product may naturally contain types of organisms more resistant to radiation than any species previously reported. Once the minimum dose for *absolute* sterility is established, the ethical manufacturer provides a greater dose for process sterilization of a product.

In our pilot studies we have employed as monitors intentionally contaminated products identical in all other respects with the marketable item, rigid vinyl dose indicators (*Ar₂58*) and integrating electrical monitoring devices.

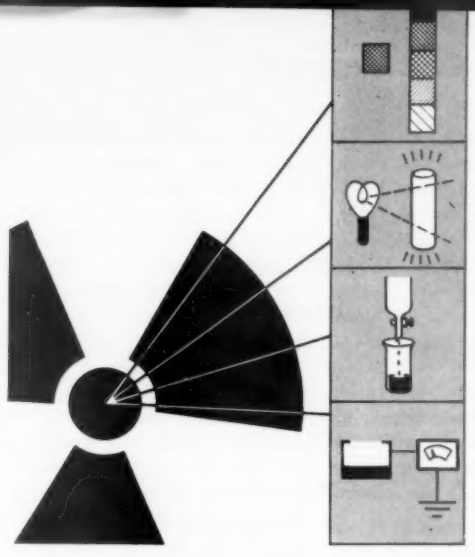
TABLE 2—Spore Survivors on Paper Disks*

Layers of disks†	*Unit-density thickness (in.)*	*Dose range*‡ *(10^6 rads)*	*Sterility tests*	
			Pos.	*Neg.*
1–4	0.704	1.7–2.0	0	5
5	0.750	1.0–1.5	1	4
6	0.797	0.6–1.0	5	0

* Disks were impregnated with a water suspension of *Clostridium tetani* spores having 10^7 viable spores per ml. † Polyethylene and cardboard. ‡ Measured with polyvinyl chloride.

NOTE ON BIBLIOGRAPHY

All references in this special report are to the bibliography on pages 75 and 76.



Total-Dose Standards

By SAMUEL I. TAIMUTY
Stanford Research Institute, Menlo Park, California

STANDARDS FOR DOSIMETRY measurements serve two functions: (1) calibration of specific dosimeters and (2) measurement of radiation field intensity in specific experimental situations. Large-dose dosimetry standards have not yet been adopted by any of the standards associations although the ferrous-ferric method is nearing official recognition by the American Society for Testing Materials (*Am59*). Nevertheless there are several methods (including the ferrous-ferric) that are well enough developed to deserve serious consideration for adoption as standards.

Examples of the dosimeter-calibration function are primary calibrations of dosimeters such as the Fricke ferrous sulfate dosimeter and recalibrations of dosimeters that are not reproducible from batch to batch (such as plastic films, glass). Examples of the intensity-standardization function are measurement of the output of electron-beam accelerators.

Standardization methods should be accurate and reproducible, and they should involve as few qualifying assumptions as possible. It is not necessary that they be convenient since standardization measurements generally need not be performed often.

Only two methods will be discussed here: calorimetry, which can serve in place of a primary standard, and the Fricke ferrous-ferric dosimeter, which can serve in place of a secondary standard. Other methods, applicable primarily to certain types of particle accelerators, have been discussed by Schuler (*Sc₁58*).

Calorimetry

Calorimetry is applicable to both absolute calibration of dosimeters and absolute measurements of source intensity. With it energy absorption in most liquids and some solids can be measured directly in terms of fundamental energy units. Measurement accuracy depends on the energy-absorption rate. With the high rates characteristic of modern electron accelerators ($>10^7$ ergs/sec), accuracies of 1–2% are obtainable with moderately simple apparatus and techniques. Comparable accuracies are obtainable in measurements of photon absorption at energy-input rates of $\sim 10^5$ ergs/sec (dose rates of $\sim 3 \times 10^5$ rads/hr in water). However, because of the low absorption rate, considerably more care is required.

Principles. Design and use of calorimeters for heat measurements have been adequately discussed (*Wh₁28, We₂45*). The same principles apply to high-energy radiation-absorption measurements. In brief, the energy absorbed by the calorimeter is determined by measurement of the temperature rise of the calorimetric fluid or solid. Temperature rise is related to energy absorption through a separate (usually electrical) calibration using a known energy input to the calorimeter.

First of all, precautions are necessary to ensure that the temperature throughout the calorimetric substance is as uniform as possible, particularly if the distribution of energy absorption is nonuniform. Thus liquids must be stirred, and solids must have high thermal conductivity. Secondly, it is necessary to ensure that heat exchange with the calorimeter surroundings is either negligible or known. Finally, it is frequently necessary to apply corrections for absorbed energy that is not converted to heat.

Adiabatic calorimeters. Two types of calorimeter are most commonly used: adiabatic and compensated. Adiabatic calorimeters provide adequate sensitivity when small energy-absorption rates are measured. Adiabatic calorimetry requires that heat transfer to or from the calorimeter be negligible. Convective heat transfer is reduced by evacuating a chamber surrounding the calorimeter or by surrounding the calorimeter with foamed plastic insulation if sufficient space is available. These methods also reduce conduction loss. Conduction loss is further reduced by mounting the calorimeter on thermally insulating supports and by using thin wire for electrical connections to external apparatus. Finally, the radiation loss is reduced by maintaining the temperature of the surroundings equal to that of the calorimeter with a heated jacket. In some calorimeters radiation loss can be reduced by providing the calorimeter with a low-emissivity (highly polished) surface and surrounding the calorimeter with a similar low-emissivity radiation shield. Not all of these measures are necessary simultaneously.

Adiabatic calorimeters have been used in calibration of the Fricke ferrous sulfate dosimeter with Co^{60} radiation (*Ho₁53, La₂54*). One group's calorimeter consists of a Pyrex bulb filled with water and containing a thermocouple (*La₂54*). The calorimeter surroundings are evacuated and a heated jacket is provided to maintain zero temperature difference between the calorimeter and its surroundings. A precision of $\pm 2\%$ is obtained at a dose rate of 2.5×10^5 rads/hr.

Another adiabatic calorimeter measures absorbed dose in polyethylene

loaded with free carbon to increase thermal conductivity (*Mi₂58*). A precision of ±1% is quoted for Co^{60} measurements at 9,000 rads/hr.

An adiabatic calorimeter that has been proposed as a primary standard for absorbed dose measurements is under development at the U. S. National Bureau of Standards (*Ha₁58*). In its preliminary form, the calorimeter consists of a graphite sphere suspended on polystyrene pegs inside a graphite shell. The graphite shell is heated to provide an adiabatic shield. An accuracy of better than 1% was obtained in a Co^{60} source at 4.75×10^5 rads/hr.

Compensated calorimeters. When the sensitivity of an adiabatic calorimeter is not needed (as with high-intensity electron beams), compensated-loss calorimeters provide adequate accuracy and considerable simplification. In such calorimeters, elaborate precautions to eliminate heat exchange with the environment are unnecessary. Heat exchange is reduced by surrounding the calorimeter with Styrofoam insulation and limiting the energy input to the calorimeter so that its temperature does not rise too far above the surrounding temperature. A correction for the remaining heat exchange is derived from the pre- and post irradiation temperature-drift curves.

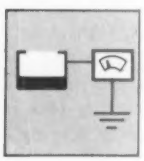
Both liquid and solid compensated-loss calorimeters have been used. The author has described a liquid calorimeter for calibration of aqueous dosimeters and solid calorimeters for measurement of electron-beam intensity (*Ta₁57a*, *Ta₁57b*). Solid calorimeters can also be used for energy-absorption measurements in nonconducting solids by making measurements with and without the solid interposed in an electron beam in front of the calorimeter (*Ta₁57b*).

Ferrous Sulfate Dosimeter

The Fricke dosimeter (*Fr29*) is the most widely used and most reliable dosimeter that has been developed to date. In fact its performance is such that it has been tacitly accepted as a secondary-standard dosimeter (*Am59*). Use of the dosimeter has been discussed by others (*We₁58*). A precision of 1–2% is readily obtainable.

The dosimeter solution is prepared by dissolving 2 gm of $FeSO_4$, 0.3 gm of NaCl (to inhibit impurity effects) and 110 ml of concentrated H_2SO_4 in enough distilled water to make 5 liters of solution. The ferric-ion yield is measured spectrophotometrically at 3,050 A. The mean of reliable yield measurements (*Ho₁53*, *La₂54*, *Sc₁56*) gives $G(Fe^{++}) = 15.6$. The yield is independent of dose rates at least up to 10^{10} rads/sec (peak rate with pulsed electrons) (*Ke57*). However, the dosimeter is unreliable at average rates exceeding 2×10^6 rads/sec because impracticably high stirring rates are required to replenish oxygen depleted in the reaction zone (*Sc₁56*). The useful range of the dosimeter is 4,000–40,000 rads. Although the range can be extended to 200,000 rads by saturating the solution with oxygen, this procedure is not recommended.

The dosimeter is most useful for routine dosimetry and as a secondary standard in photon measurements at rates up to 1.5×10^6 rads/hr. Higher rates require special mechanisms to reduce the timing error (for exposures of 4×10^4 rads) to an acceptable value. The dosimeter can be used at higher rates with electrons if the ratio of the irradiated to the total volume is sufficiently small and if adequate stirring can be provided.



Rate Measurements

By SAMUEL I. TAIMUTY, *Stanford Research Institute, Menlo Park, California*

IN USING RADIATION sources, there is frequent need for continuous or periodic measurement of dose rate or source intensity. Examples are the measurement of photon intensity or electron-beam current for monitoring purposes. In general, rate measurements are more conveniently made with continuously indicating devices as distinguished from integrating devices in which one records a quantity delivered in a measured time interval. However, the latter technique is sometimes used. Methods are available for measurement of electron current, and photon radiation intensity or dose rate.

Faraday Chambers

A Faraday chamber measures electron current by measuring the total charge collected in a given time in a chamber that totally absorbs the electron beam. It provides an absolute measurement of current if properly designed. Because it is preferably (for precision) an integrating rather than a continuous device, it is best used for periodic current calibrations. An additional disadvantage is that even when it is operated as a continuous device, its use for current monitoring is possible only under limited circumstances.

Faraday chambers can be used throughout the currently available range of electron energies—from a few to hundreds of millions of electron volts. Brown and Tautfest have described the design, construction and use of chambers up to 300 Mev (*Br₂56*). In its simplest form a Faraday chamber is a narrow-apertured chamber of conducting material with a stopping wall perpendicular to the beam thick enough to absorb the electrons. The collected charge either is accumulated in a precision capacitor for a given time, after which the capacitor potential is measured, or is bled to ground through a known resistance, the potential drop across which is measured continuously. One must avoid errors due to leakage, loss of backscattered electrons, ion collection from surrounding air and, at higher energies, loss of charge through shower penetration. "Shower penetration" refers to loss of electrons released from the chamber by energetic bremsstrahlung photons.

Leakage loss can be minimized by properly insulating the chamber and

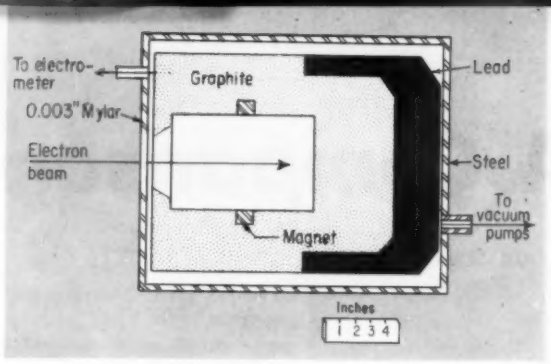


FIG. 1. FARADAY CHAMBER for high-energy electrons uses graphite and lead to absorb electrons and photons

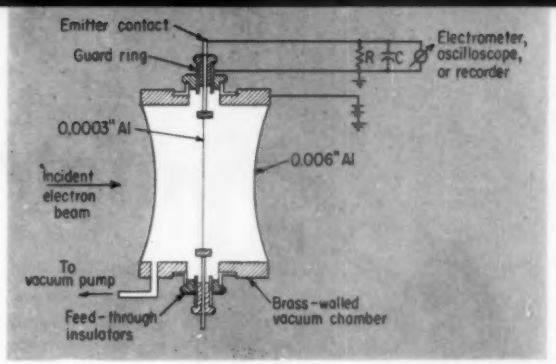


FIG. 2. SECONDARY-EMISSION CHAMBER monitors electron beam by observing current of secondaries leaving central foil

minimizing the potential difference between the chamber and ground. Three steps reduce the loss of backscattered electrons: (1) A reentrant aperture design reduces the escape solid angle. (2) The surface with which the beam first collides is made of low-Z material (generally graphite) to minimize the cross section for backscatter. (3) A permanent magnet can be installed at the aperture to prevent the escape of low-energy secondaries.

Collection of ions from the surrounding air can be eliminated by enclosing the chamber in a vacuum. High-vacuum techniques may be required for precise work. Loss of charge through shower penetration can be made negligible by increasing the size of the chamber (*Br₂56*).

A chamber design that makes use of these principles is shown in Fig. 1.

Secondary-Emission Chambers

A secondary-emission chamber measures electron current by the secondary electrons emitted from a foil on passage of an electron beam through the foil (*Ta₁59a*, *Ta₂55*). In the most recent design (Fig. 2) a single aluminum foil is placed inside a vacuum chamber between entrance and exit windows through which the electron beam passes (*Ta₁59a*). The emitter foil is 0.0003 in. thick and window foils are 0.006 in. thick so that electron absorption in the three foils is negligible at the energies of interest. Thus, the device can be used as a continuous transmission monitor.

The foil is insulated from the chamber and maintained at a negative potential with respect to it. The secondary-emission current is measured in a series circuit containing the emitter foil, the chamber and the polarizing potential. Complete current collection is obtained at polarizing potentials less than 100 volts. The current from both surfaces of a single aluminum emitter foil is about 5% of the primary (transmitted) current (*Ta₁59a*, *Mi₁55*). However, the ratio depends on foil composition and can depend on the condition of foil surfaces. Hence secondary emission chambers should be calibrated against a good Faraday chamber at the energies to be monitored.

Such chambers have performed reliably at pulsed (linear accelerator) current densities of 150 ma/cm² and average currents as high as 120 μa (270 μa/cm²). At higher average current densities, it is advisable that the windows be cooled.

Ionization Chambers

Ionization chambers have a long history of use in X- and gamma-radiation measurements. Only recently, however, have designs suitable for use at large dose rates appeared. Theory, design and use of ionization chambers have been discussed (*Sp56*, *Bo₁56*). Cavity chambers designed in accordance with the Bragg-Gray principle provide the most easily interpretable measurements. Accurate and precise absorbed-dose-rate measurements can be made with such chambers at dose rates up to 10^7 rads/hr in the wall material. Measurements can be made at slightly higher rates if suitable corrections for reduced ion-collection efficiency are applied. At higher dose rates, low-pressure or vacuum chambers based on secondary electron emission can also be used (*Bo₁56*). However, such chambers must be calibrated.

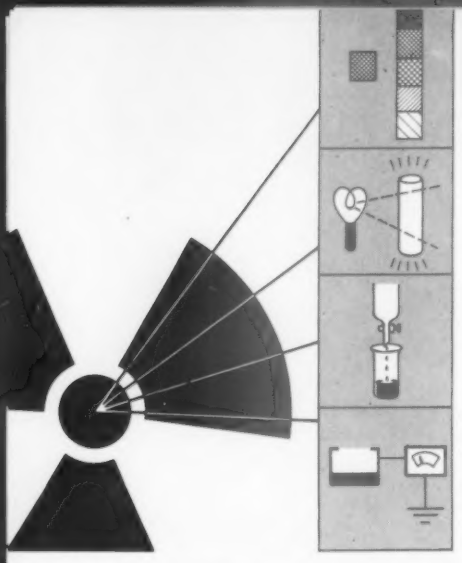
Two chamber designs suitable for use at large dose rates have appeared recently. One is a spherical graphite chamber suitable for use with Co^{60} gamma radiation (*Wy57*, *Ha₄58*). With a collecting potential of 1,000 volts, the currents collected are within a few per cent of saturation currents at a dose rate of 10^6 rads/hr.

A similar spherical graphite chamber for use at higher rates has smaller electrode spacing (*Ta₁59a*). As a result this chamber provides essentially saturation current collection with a chamber potential of 600 volts at a dose rate of 10^7 rads/hr. This chamber was also designed for prolonged continuous exposures to intense radiation fields without deleterious effects from radiation damage. The chamber and 3 ft of the connecting cable are constructed entirely of inorganic materials (graphite, ceramic insulation and metal). Because the electrical resistance of ceramic insulators is not as high as that of good organic insulation, it was necessary to provide a guard electrode to bypass leakage.

Parallel-plate ionization chambers can be used for transmission measurements of continuous and pulsed electron beams at rates up to 10^7 rads/hr. However, because of this dose-rate limitation, secondary-emission chambers usually prove more suitable for electron measurements.

Semiconductor Devices

Direct-read-out semiconductor devices have recently been developed for both gamma and neutron measurements. A CdS photovoltaic cell is useful for X- and gamma-ray measurements (*Ho₂56*). The use of a commercially available silicon solar cell for gamma-radiation measurements has also been reported (*Mo58*). The cell, consisting of an np junction formed by diffusion of boron into 0.1-ohm-cm n-type silicon, is capable of measurements at dose rates of 400–10^8 r/hr. Radiation damage limits the useful life to a total exposure of the order of 10^9 r, but the cell can be healed by annealing.



A Comparison

By PAUL SCHALL, Jr.*
Battelle Memorial Institute, Columbus, Ohio

CHOOSING THE RIGHT dosimetry system for a particular situation requires a critical evaluation of available data. There is no substitute for complete familiarity with the characteristics of the dosimeter selected. Lack of familiarity can obliterate all the potential advantages of one system over another.

The table that follows is compiled from questionnaires sent to different experts. We cannot expect them all to use the same criteria for their answers. Thus I have undertaken a critical comparison.

Accuracy

It is easy to be too optimistic with respect to accuracy. One should perhaps consider the percentages given as reproducibility rather than accuracy. For example, all photon dosimeters except calorimeters require calibration directly or indirectly against standard sources, and $\pm 2\%$ standard sources, particularly at large dose rates, are essentially nonexistent.

Furthermore, many reproducibility values are undoubtedly obtained in exceedingly well controlled experiments. Questions arise as to how nearly these values can be achieved for more routine dosimetry.

Reproducibility. One must bear in mind that systems such as ferrous-sulfate, ceric-sulfate, polymerization and halogenated-hydrocarbon-dye dosimeters are strongly influenced by small amounts of certain impurities and exposure to ordinary light. In contrast, glass dosimeters appear to offer a better possibility for routine use without extreme care.

Of the other integrating systems, degradation of luminescent materials and darkening of plastics offer considerable promise with regard to good reproducibility with a minimum of precautions. The nitrous-oxide system appears to offer relative simplicity and good reproducibility—but to my knowledge it has not been developed to the point where recommendation can be made for its routine use.

Of the instrumental systems, calorimeters probably require greatest care to achieve good accuracy and reproducibility. Others are subject to radiation-induced electrical problems and more common types of electrical "gremlins." By and large, however, they can be expected to give good performance provided reasonable precautions are taken. Of these three systems the ion chambers have been used most extensively. They can be judged most reliable at this time.

Microbial systems yield the poorest reproducibility and their use appears to be limited to specialized applications.

Dose and Dose Rate

In general, for operation in the intermediate ranges for dose (10^5–10^7 rads) and dose rates (10^4–10^6 rads/hr) there is a wide choice of dosimeters. However, for doses greater than 10^7 rads the choice is limited largely to luminescence degradation and nitrous oxide, both of which are in relatively early stages of development. It should be mentioned, however, that the dose range given for glasses is quite conservative. Some of the newer glasses being studied show capabilities of going to at least 10^9 rads (*Ki58a*). These are also in an early stage of development.

Over-all, luminescence degradation appears to be the best bet, currently, for those who must measure high doses with an integrating device. Of course if external connections can be provided, integration of the output of rate-measuring devices can be used. With photovoltaic cells, ion chambers and Cerenkov detectors an upper dose limit is imposed by permanent damage produced by radiation. The useful range can be extended by use of radiation resistant materials.

Rate dependence. The information on dose rates must be examined closely for two reasons. First, the ranges given obviously do not imply dose-rate independence. Many of the systems are rate-dependent but can give reliable measurements at high dose rates if properly calibrated. Some of the systems are, however, independent of rate over the ranges given. I believe that plastics darkening, photography, photovoltaic cells, glass, dyed plastics, halogenated dyes, ceric sulfate, and ionization chambers exhibit dose-rate dependence in the ranges indicated for each. Ranges given for others, particularly ferrous sulfate, nitrous oxide, and quinine, probably represent dose-rate-independent ranges. At dose rates above $\sim 10^8$ rads radiation heating is important.

Costs

For the lowest-cost system, polymerization, it must be remembered that this is essentially a go–no-go dosimeter. With rate devices manual measurements can be made with relatively small investment. However, if continuous recording or electronic integration is desired, equipment costs can get into the range of thousands of dollars.

Equipment costs reflect individual judgments as to how elaborate the equipment should be. To a large extent, however, differences in costs are due to real differences in system requirements. For example, response of the methylene-blue system can be measured by a simple colorimeter, whereas costs for the ferrous-sulfate dosimeter apparently apply to an ultraviolet spectrophotometer. Optical readout could be on a less expensive instrument by using a complexing agent for ferric ion which permits measurement in the visible region. Alternatively titration offers low equipment costs.

For ceric sulfate the choice between two methods is dictated by the range

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# of Dosimetry Methods

of doses to be measured. In general, throughout the list of photon dosimetry systems, more costly equipment gives returns in increased convenience, accuracy or both.

Time Requirements

One must consider over-all time requirements, which include materials preparation and delay between irradiation and measurement as well as measurement time. In large-volume use differences can be important.

Instrumental monitors are capable of fully automated, instantaneous readout. However, there are many applications—for example, irradiation of packaged materials—in which these systems are not suitable or at least do not provide all information needed. In these cases dosimeter systems such as plastics darkening, glasses, luminescence degradation, and dyed plastics can be maintained as shelf items with extended life, and they provide the convenience of rapid readout. In terms of rapid measurement, one shortcoming of the glasses is the time required for postirradiation heat treatment frequently used to stabilize the dosimeter. However, where speed is of prime importance this step can be eliminated—at least for some glasses—by proper calibration and accurate control of time between irradiation and readout. Recent developments indicate that heat treatment can be shortened to ~10 min (*Nu59*).

Permanency of Change

For solid-state systems in general one can expect to circumvent instability problems by suitable, uniform heat treatment. Except for the inconvenience and time for heat treating, these can be very satisfactory.

A word of caution is in order regarding 100% permanency for various chemical systems. This should not be interpreted as indication that delay between irradiation and readout is of no consequence. While radiation-induced change may be permanent, it is sometimes supplemented by additional change after irradiation. For example, the effect of exposure to light on the ceric-sulfate and ferrous-sulfate systems is well known.

Temperature Effects

Temperature effects are not a serious problem over the range covered in normal room-temperature irradiations. However, where large dose rates are encountered or measurements are to be made on site in an experiment at elevated temperatures, this factor must be considered.

Of the chemical dosimeters, the nitrous-oxide system is probably best for high-temperature applications. Information available on this system indicates temperature independence up to about 250° C. Ceric- and ferrous-sulfate systems are limited to temperatures below about 70° C.

Because of annealing, glass, luminescence degradation, and plastics-darkening systems show definite temperature dependence. However, a suitable postirradiation heat treatment above the highest irradiation temperature may eliminate the problem.

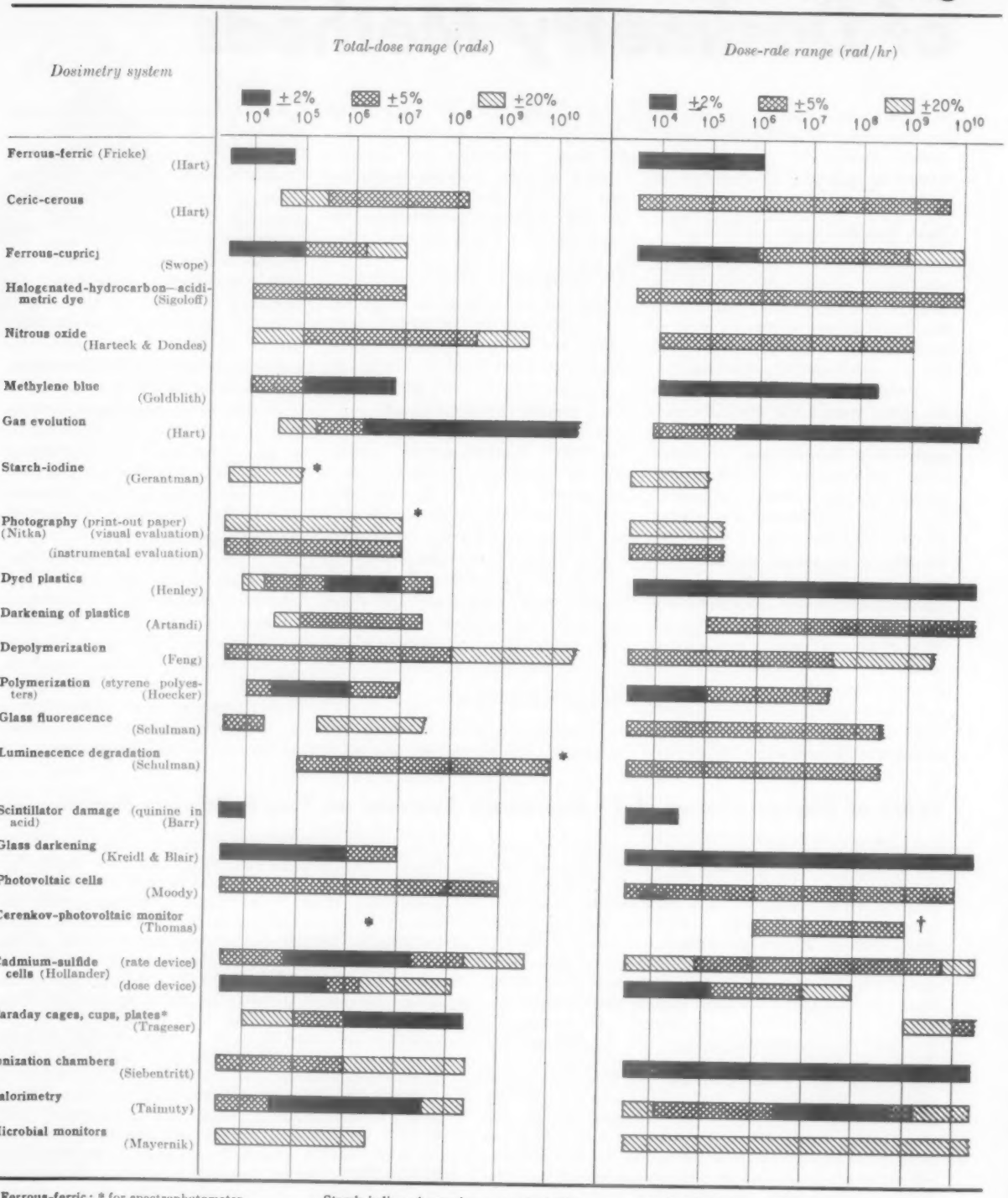
One other type of temperature effect should also be mentioned: the effect of readout temperature. With ferrous sulfate, for example, the extinction coefficient for ferric ion is temperature dependent. Normal room-temperature variations and heating produced during prolonged residence time in the spectrophotometer during readout can cause appreciable error.

Table of Characteristics of 24 Dosimetry Systems on Two Following Pages

EDITORS' NOTE TO THE FOLLOWING TABLE: Column headings in the table are abbreviations of the following detailed questions: **1.** Over what range of TOTAL DOSE do you consider the method usable? Please shade the following bar to indicate regions in which the method is accurate to ±2%, ±5%, ±20%. **2.** At what DOSE RATES do you consider the method usable? Please shade the following bar to show ranges in which accuracy is ±2%, ±5%, ±20%. **3.** What is the cost of equipment required to make this method available for routine dosimetry? (Assume that the system will not make use of apparatus borrowed for the purpose.) **4.** What is the approximate cost per measurement of materials required for routine measurements? **5.** With the system established, how much time is required to make the following numbers of routine measurements? Suppose, for example, that during a single operating day you are to make 1 measurement or 20 measurements or 100 measurements. Exclude waiting time. **6.** (a) How much delay *must* there be between exposure and reading? (b) How much delay *can* there be between exposure and reading? (c) What fraction of the change with exposure is permanent? **7.** What do you find are the principal advantages of the method? **8.** What are the greatest disadvantages and inconveniences of the dosimetric method?

Here are the names and affiliations of people who sent the answers: CHARLES ARTANDI, Ethicon, Inc., Somerville, N. J.; NATHANIEL F. BARR, Sloan-Kettering Inst., N. Y., N. Y.; GERALD E. BLAIR, Bausch and Lomb Optical Co., Rochester, N. Y.; SEYMOUR DONDES, Rensselaer Polytechnic Inst., Troy, N. Y.; PAUL Y. FENG, Armour Research Foundation, Chicago, Ill.; L. H. GEVANTMAN, USN Radiological Defense Laboratory, San Francisco, Calif.; SAMUEL A. GOLDBLITH, Massachusetts Inst. of Technology, Cambridge, Mass.; EDWIN J. HART, Argonne National Laboratory, Lemont, Ill.; PAUL HARTECK, Rensselaer Polytechnic Inst., Troy, N. Y.; ERNEST J. HENLEY, Columbia University, N. Y., N. Y.; FRANK E. HOECKER, Univ. of Kansas, Lawrence, Kans.; L. E. HOLLANDER, Jr., Victoreen Instrument Co., Cleveland, O.; NORBERT J. KREIDL, Bausch and Lomb Optical Co., Rochester, N. Y.; JOHN J. MAYERNICK, Merck and Co., Rahway, N. J.; JERRY W. MOODY, Battelle Memorial Inst., Columbus, O.; H. F. NITKA, Ansco, Binghamton, N. Y.; JAMES H. SCHULMAN, Naval Research Laboratory, Washington, D. C.; CARL R. SIEBENTRITT, Jr., Bendix Aviation Corp., Cincinnati, O.; SANFORD C. SIGOLOFF, Edgerton, Germeshausen and Grier, Las Vegas, Nev.; GLADYS SWOPE, Argonne National Laboratory, Lemont, Ill.; SAMUEL I. TAIMUTY, Stanford Research Inst., Menlo Park, Calif.; C. C. THOMAS, Jr., Westinghouse Electric Co., Pittsburgh, Pa.; DAVID A. TRAGESER, High Voltage Engineering Co., Burlington, Mass.

Dosimetry Systems: 24 Methods for Measuring



Ferrous-ferric: * for spectrophotometer
Ceric-cerous: * titration method; † spectrophotometer method
Halogenated-hydrocarbon-acidimetric-dye: * all times include data reduction to final answer
Nitrous oxide: * Pyrex vessel; † quartz vessel; ‡ special apparatus could cut the time by a factor of 10
Gas evolution: * times depend on intensity of source and composition of solution since liquids other than water can be used [see E. J. Hart, S. Gordon, NUCLEONICS **12**, No. 4, 40 (1954)]
Starch-iodine: * actual accuracy is ±10%
Photography: * total range for 1–3-Mev photons can be extended by factor of 50 with 3-in. lead filter
Dyed plastics: * times assume no use of automatic reading device
Polymerization (styrene polyesters): * no equipment is required for reading; chemical balance, beakers and flasks are required for preparation; measurement cost is for actual materials; preparation of 100 dosimeters requires ~1 hr
Glass fluorescence: * Glass can be reused after annealing for 5 hr at 400° C.
Luminescence degradation: * Range can undoubtedly be extended upward (and probably downward) with other materials. † After heat treatment (1 hr, 100° C)
Glass darkening: * delay between exposure and reading depends on particular glass dosimeter chosen and precision desired; F-0621 glass (Bausch and Lomb) is relatively stable when measured at 3,500 and 4,000 A for exposures in the 10^5-rad range; † fading is <5% 2 mo after irradiation; fading increases with dose and wavelength, but

Large Radiation Doses (for discussion see two preceding pages)

Equipment cost (dollars)	Materials cost (dollars per measurement)	Time for measurements (min)			Delay time (min)		Fraction of change that is permanent (%)	Advantages	Disadvantages
		1	20	100	(must be)	(can be)			
2,500*	0.01	2	20	100	0	10^5	100	high accuracy; direct analysis without further treatment; solution can occupy space and volume of sample	need of operator experience; need for care in irradiation
100* or 2,000†	0–05	30	200	1,000	0	10^3	100	simplicity; accuracy	need for titration at high doses and rates
2,000	0.01	5	40	200	0	10^3	100	extends range of ferrous-ferric system	solutions less stable than ferrous-ferric ones; nonlinear at high doses
2,000	0.10	15	80	300*	30	∞	100	size; insensitivity to neutrons; range; ease of evaluation	need for production know-how; need for glass container (research is looking for a suitable plastic vial)
500–1,000	0.25* or 5†	30	500	2,500‡	0	∞	100	temperature range—80°–200° C; decomposition products don't interact; wide dose and rate ranges; unlimited shelf life	need for vacuum and liquid air; need to break seals in vacuum
250	0.01–0.02	15	60	180	0	10^5	100	ease and simplicity for routine work	need for standardization of each batch of dye
200	<0.01	*	*	*	0	$>10^3$	100	usefulness for continuous source monitoring; response to all radiations including neutrons	need for individual gas-collection system for each measurement
300	0.25	1	15	60	60	10^3	100	simplicity of colorimetric measurement; little need for attention to purification; range adjustment by varying iodine concentration	energy dependence; starch fraction must be soluble; need of time lag for color growth; not tissue-equivalent (but it can be made so)
0 400	0.10	0.3	5	20	0	>5,000	100	speed; cost; simplicity; lack of need for processing after exposure	lack of commercial availability
2,300	0.01	1	5	20*	0	∞	100	convenience; cost; simplicity	variation of accuracy with different batches of plastics
600–1,200	0.004	10	20	60	10	1,440	>80	simplicity; cost; applicability of visual evaluation	need for standard color development
200	0.02	3	60	200	0	10^3	100	wide range (4 decades for one dosimeter; 6 decades for system)	limited accuracy; need for temperature control or correction and standard reading time
0*	0.05*	0.1	3	10	0	∞	100	go-no-go system; wide range; cost; lack of need for auxiliary equipment	decrease of sharpness of index at highest doses; requirement of cold storage for periods of a month or more
250–350	0*	0.5	10	50	15	$>5 \times 10^5$	80–100	convenience; ruggedness; solid, indefinite storage, dosed or undosed	useful at intermediate dose range (10–10,000 r)
200–300	0.05–0.10	0.5	10	50	0	$>4 \times 10^4$	>95†	smallness; solid; long-term storage, dosed or undosed; use of cheap, readily available chemicals; wide range; ability to reread; simplicity	need for heat treatment (if one is to avoid *all* recovery effects)
1,000	0	1	20	100	0	10^3	100	speed; convenience; reproducibility; sensitivity	logarithmic response
250	0.30	1	15	60	0	10^5*	50–95†	simplicity; accuracy; cost; ruggedness	need for calibration; limits of dose range
100*	0*	†	†	†	0	0	†	simplicity; speed	lack of total-dose response
50	0	‡	‡	‡	0	0	‡	simplicity; cost; lack of time delay; logarithmic response	need for radiation energy great enough to produce Cerenkov radiation (for electrons in water, 0.26 Mev)
600 10	0.50–2	0.2	3	15	~0.5*	4×10^4	(little)		need for more research to establish feasibility
200	0	0	0	0	0	—	0	electrical nature; applicability to continuous monitoring; lack of need for recalibration	failure to tell absorbed dose directly; requirement of careful original design and calibration; not go-no-go
<500	0	*	*	*	—	—	—	direct reading; availability of recycling; unlimited shelf life	
2,500	—	—	—	—	0	—	0		suitability for standardization only; need for skilled personnel
200* or 2,500†	1'	15	120	600	10^4	∞	100	direct measurement of sterilization; applicability for establishing a sterilization process and for witnessing sterilization during irradiation	need for 7 days to obtain results; need for bacteriological training

precision is still within 5% if measured a few hours after irradiation; in general, ~95% of change is permanent at low dose when measurement is with short wavelengths, and 75% of change is permanent with doses of $10^3 - 10^7$ rads when measured at 5,000 A; this is true only for this specific system; for other glass dosimeters fading may result in loss of 50% or more of change with exposure

Photovoltaic cells: * $5–10 for a silicon solar cell; $100 for an adequate voltmeter; after 10^9 rads total dose silicon cell must be replaced; † device reads rates, essentially instantaneously

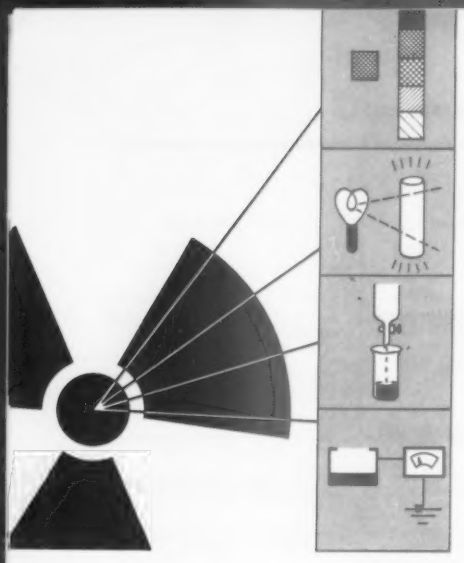
Cerenkov-photovoltaic monitor: * wide range of total dose has not been investigated; device was exposed to ~1.8×10^9 rads at 3.4×10^2–1.7×10^4 rads/sec with no apparent damage; † reproducibility is ±5%; absolute accuracy has not been determined; ‡ device reads rates instantaneously

Cadmium-sulfide cells: * reading as a dose device is probably very critical for 0.5 hr after exposure

Faraday cages, plates, cups: * these systems are not dosimetry methods in themselves, but rather beam-measuring devices for electrons only; must be used with energy sensors to determine dose

Ionization chambers: * times vary with flux and total dose

Microbial monitors: * assuming normal bacteriological facilities available; † assuming laboratory facilities available but bacteriological facilities have to be provided



Chemical Dosimetry

By DAVID E. HARMER, *The Dow Chemical Company, Midland, Michigan*

CHEMICAL DOSIMETRY offers a range of flexibility unmatched by any other dosimetric system: choice of gaseous, liquid, gel or solid states; dose ranges from ~ 10 to $> 10^9$ rads; and, within limits, choice of density.

The accompanying table illustrates the variety of available methods. Although only six or eight out of the more than forty methods listed have gained widespread use (the favored ones are indicated by arrows), the less popular methods may be preferable for special situations. The references (see p. 75 for bibliography) were selected to provide more complete information where desired.

Because chemical-dosimeter systems usually involve chain reactions or extremely low concentrations, purity of reagents and glassware is of utmost importance. Organic reagents are purified by distillation or recrystallization. For highest precision, double- or triple-distilled (not deionized) water is used. If less precision is tolerable, ordinary distilled water can often be used.

Liquid Systems

The chemical dosimeter that has enjoyed the greatest amount of research effort and is the most nearly standard is the Fricke dosimeter. Its sensitivity can be increased by tracer amounts of iron-59 to aid in the analytical steps. On the other hand, the addition of a copper salt decreases the oxidation rate, allowing a twentyfold increase in the usable dose range. Use of the iron complex of 1:10 phenanthroline during irradiation allows analysis by visible instead of ultraviolet spectrophotometry and causes the iron to be reduced rather than oxidized during irradiation.

Another popular dosimeter makes use of the reduction of ceric sulfate. It has the advantage over the Fricke system of being unaffected by the presence or absence of oxygen in solution. Since the G value is nearly six times lower than that of the iron system, and since higher concentrations can be used, the effective range is much larger. The addition of thallous sulfate to the ceric system produces a dosimeter that is intermediate in yield between the ceric and ferrous systems.

Oxalic acid (without metallic salts) as a dosimeter is relatively new. Its large dose range and relative insensitivity to impurities make it attractive for further investigation.

Iodide salts are readily oxidized by radiation to yield free iodine, which produces a deep color with starch. However, their nonlinearity with dose and low analytical precision make them generally undesirable.

Benzene or benzoic acid is quantitatively hydroxylated by irradiation in aqueous solution. The analysis is complicated by the use of Folin's reagent to develop the color, although in some cases spectrophotometry or spectrophotofluorometry can be used directly on the dosimetric solution with good results.

Of the dye solutions, the most fully developed is aqueous methylene blue. The fading of the blue coloration can be conveniently followed with a laboratory colorimeter. Accuracy is less than for ferrous or ceric solutions.

Of the chlorinated hydrocarbons, chloroform and carbon tetrachloride are particularly popular. In some of these systems, the HCl liberated during decomposition is measured electrically, but, in the great majority of cases, dissolved dye is used as a reaction indicator. In some cases, the dye is destroyed or changed to a colorless structure by the fragments produced in the radiolysis of the chlorine-containing solvent. In these cases, the system is similar to those using dye in water or in inert organic materials, except that the radiosensitivity of the chlorinated hydrocarbon accelerates the dye decomposition, resulting in a more sensitive system. As an example, methyl yellow has an exposure range more than 10^4 shorter in chloroform than in cumene.

In other dosimeter systems, the dye included in the chlorinated solvent functions purely as a pH indicator. These systems may have one or two liquid phases present, depending upon the amounts of organic solvent and water. A stabilizer and predetermined amounts of alkali are usually included to control the dosimeter range.

Chlorinated hydrocarbon dosimeters, in general, suffer from the fact that chain reactions are involved, making them particularly sensitive to impurities and atmosphere. Alcohol or certain phenols are usually necessary in the system as stabilizers.

Combinations of chlorinated hydrocarbon dosimeters are valuable in assessing neutron dose in mixed-radiation fields. The neutron response varies with the proportion of water in the make-up of the dosimeter. Thus a pair of dosimeters might include one containing nearly pure tetrachloroethylene and the other, a large portion of water.

Gel Systems

Gel systems are particularly useful for measuring dose as a function of depth for electrons or soft X-rays. A gel is formed by combining one of the dye systems with gelatin or agar. After exposure, slices of the gel are examined for dye intensity in various locations. Electrical probes can also be used if a chlorinated hydrocarbon is a constituent of the gel.

Dosimetric method*	References	Reagents	Max. dose (rads)	Conversion Value, G	Type of radiation	Method of analysis
LIQUID SYSTEMS						
Methods using iron salts						
▶ Fricke	Am59 We152 Ho153 We156	Air-sat'd aqueous sol'n: 0.001 M $FeSO_4$, 0.001 M NaCl, 0.4 M H_2SO_4	4×10^4	15.6	β, γ	U-v spectrophotometer at 3,050 A
Fricke with isotopic tracer	Ru53	As above + Fe^{59} tracer	Good down to 0–100	15.6	β, γ	Conversion to thiocyanate complex, extraction with *i*-amyl alcohol, counting of Fe^{59} in each layer
▶ Cu-modified ferrous	Ha454	Air-sat'd aqueous sol'n: 0.001 M $FeSO_4$, 0.005 M H_2SO_4, 0.01 M $CuSO_4$	8×10^5	0.66	γ	U-v spectrophotometer at 3,050 A
Ferrine	Le253 Pu53 Pu55	Air-free sol'n. of ferric 1:10 phenanthroline in aqueous 0.4 M H_2SO_4	3×10^4	10.0 in 0.4 M H_2SO_4	γ (n, with H_3BO_3)	Buffer to *p*H 4 with sodium acetate, use spectrophotometer at 5,100 A
Ceric sulfate						
▶ Ceric sulfate	Da153 We152 Ha258 Wh257 Ni155	0.004 M $Ce(NH_4)_4(SO_4)_4$, 0.4 M H_2SO_4 in triple-distilled water	10^6 (10^8 under special conditions; yield is not linear)	2.4	β, γ	U-v spectrophotometer at 3,200 A, or by titration
Tl-modified ceric	Sw56	Same as above, plus 10^{-4}–10^{-3} mole/l of thallous sulfate, H_2O redistilled from alkaline permanganate		7.92	γ	U-v spectrophotometer at 3,200 A
Oxalic acid	Dr59	Commercial-grade oxalic acid in aqueous sol'n; concentration chosen to cause <30% use of reagent during exposure	1.6×10^5 (1.6×10^6 minimum)	4.9	γ, pile radiation	Formation of the cupric-benzidine complex after irradiation, u-v spectrophotometer at 2,490 A or permanganate titration
Iodide systems						
Iodide	J53 Le250	KI or KI–starch solution		Nonlinear	X, γ	Photocolorimeter or by color of starch complex
Iodide with isotopic tracer	Ru53	Acidified aqueous potassium iodide + I^{131} tracer		Lower than for ferrous	γ	Extract I_2 with CS_2, count I^{131} in each layer
Benzene and benzoates in water						
Sodium benzoate	Da251	0.5% in water	6×10^4		X, γ	Add Folin's reagent, buffer, heat, measure colorimetrically
Calcium benzoate	Ar158c	10^{-4} M calcium benzoate	100	0.63	X, γ	Spectrophotofluorometry; excite at 2,900 A, read at 4,000 A
Benzene-water	Ca251 Da251 Wr252	Benzene-saturated water	6×10^4		X, γ, n	Spectrophotometer measurement directly on irradiated sol'n at 2,700 A, or add Folin's reagent, buffer, heat, measure colorimetrically
Dye solutions						
▶ Methylene blue	Da153 Go52 Da257 La158	1 gm/l methylene blue in water	6×10^6		X, γ, β	Colorimeter
Tetrazolium salt	Gi49	Aqueous solution of 2,3,5-triphenyl-tetrazolium chloride, *p*H 5.5–6.6	3×10^4 minimum		X, α	Formation of water-insoluble red formazan
Leuco triarylmethane	Ar158a Ar158b	10^{-4} M 4,4'-(5-chloro-2-thenylidene)bis [*N*,*N*-dimethyl-aniline], 10^{-4} M $Fe(NH_4)_2(SO_4)_2$, 0.1 M NaCl, 7×10^{-3} M HCl	2×10^5	1	X, γ	Spectrophotometer at 6,330 A
Methyl yellow	Ki58a Ki58b	0.5 gm/l methyl yellow in cumene	10^5		X, γ	Spectrophotometer at 4,060 A
Chlorinated hydrocarbon systems—1-phase						
Methyl yellow	Cl55	4×10^{-4}–5×10^{-5} M dye in $CHCl_3$ or CCl_4	3×10^5	8–21	X	U-v spectrophotometer at 3,050 A
DPPH	Ch253	Diphenyl picryl hydrazyl in $CHCl_3$	100 min to high doses	7.6	X, γ	Photometer
2-Hydroxy-4-nitro-phenylazo-β-naphthol	Cl55	2×10^{-4} M dye in ethanol containing 20–80% $CHCl_3$ or CCl_4	10^4	34–190	X	Spectrophotometer at 5,900 A
Resazurin	Cl55	1×10^{-4} M dye in ethanol containing 20–80% $CHCl_3$	9×10^3	6–18	X	Dilution with ethanol, spectrophotometer at 6,120 A

* The symbol ▶ indicates those methods that are most widely used.

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Chemical Systems for Dosimetry (*Continued*)

*Dosimetric method**	*References*	*Reagents*	*Max. dose (rads)*	*Conversion value, G*	*Type of radiation*	*Method of analysis*
		LIQUID SYSTEMS (cont.)				
Chlorinated hydrocarbon systems—1-phase (cont.)						
Resazurin	*Cl55*	1×10^{-4} M dye in ethanol containing 20–80% CCl_4	1.5×10^3	60–142	X	Dilution with ethanol, spectrophotometer at 6,120 A
Dithizone	*Cl55*	5×10^{-5} M dye in CCl_4	600	31.4	X	Spectrophotometer at 6,150 or 4,400 A
Dithizone	*Cl55*	5×10^{-5} M dye in $CHCl_3$	600	18.4	X	Spectrophotometer at 6,150 or 4,400 A
Bromcresol green	*Ro₁55*	$CHCl_3$ or CCl_4 with alcohol, KOH and bromcresol green	2×10^3 for $CHCl_3$, 10^3 for CCl_4		X, γ	Visual comparison
Single-phase aqueous, chlorinated hydrocarbon dye	*Ta₂55*	Water saturated with chlorinated hydrocarbon, resorcinol, dye	20 minimum		X, γ, n	Color change
Chloroform or tetrachloroethylene	*Si56*	$CHCl_3$ or $CCl_2{:}CCl_2$ with ~0.2% hexylresorcinol or 2,6-di-tert-butyl-4-methyl phenol	2×10^5		γ; insensitive to n	Extraction with chlorophenol red solution followed by titration with 10^{-3} N NaOH or spectrophotometer
Chloral hydrate	*An50* *An57* *Hi₁56*	0.001–1 M chloral hydrate dissolved in conductivity water	10^4 or more		X, γ	Electrical conductance cell with tungsten electrodes, Q-meter or chloride analysis
Chlorinated hydrocarbon systems—2-phase						
Chloroform-water	*Ka52*	3 parts $CHCl_3$, 1 part H_2O (double distilled), 0.15% alcohol	10^3		X, γ	Q-meter
▶ Chloroform-dye	*Ta₂51* *Ta₂54* *Ta₂55* *Ta₂57* *Ta₂58*	Purified $CHCl_3$, resorcinol (0.2–2.0%) or ethanol (0.2%), water (about ⅓ of total) with bromcresol purple, *p*H adjusted	Very low to 10^6		X, γ	Visual comparison
		GEL SYSTEMS				
Starch-iodide gel	*Ge57*	KI-starch in 1% agar			X, γ	Gel is cut into sections, examined colorimetrically
Methylene-blue gel	*Da₂50* *Da₂51*	0.001–0.003% methylene blue in 1% agar, air-free water	4×10^4		X	Spectrophotometer
Methylene-blue benzoate gel	*Da₂50* *Da₂51*	1% agar, 1% sodium benzoate, 0.2% benzoic acid, 0.003% methylene blue, air-free water			X	Spectrophotometer
Resazurin gel	*Go52* *Pr₂50*	8 ml of a 14–67 mg % sol'n (mg/100 mg sol'n) of resazurin per liter of 2% agar sol'n, air-free water			β	Visual inspection
Phenol-indo-2:6-dichlorophenol gel	*Da₂50* *Da₂51*	0.001% dye in agar or gelatine, air-free water	6×10^4		β, X	Visual inspection or spectrophotometer
2,3,5-triphenylazolium chloride gel	*Go52*	8 ml of 14 mg % dye to 1 liter of 2% agar			β	Visual inspection
Trichloroethylene-dye, gel	*Ge57* *Pe₂58*	1% agar gel with trichloroethylene and bromcresol purple		135	X	Spectrophotometer
Chloral hydrate gel	*An57*	0.05 M chloral hydrate in 0.5–0.75% agar (methyl red can be added, 3×10^{-3} gm/l)	8×10^3		X, γ, β	Spectrophotometer at 5,400 A, if dye is used, or glass-electrode *p*H meter, or electrical conductivity (tungsten electrodes)
		SOLID SYSTEMS				
▶ Dyed plastic film	*He₂51*	Cast 0.0016-in. film from 4% solution of polyvinyl chloride (Geon 101) in chlorobenzene with 0.01–0.2% methyl violet	10^7		X, γ	Spectrophotometer at 6,000 A (uniform thickness, clarity are important)
▶ Cellophane-dye	*He₂54* *He₂56* *Nu58*	Blue cellophane, commercially available from Du Pont, contains dimethoxydiphenyl-bisazobis-8-amino-1-naphthol-5,7-disulfonic acid, as dye (Du Pont 300 MS light-blue cellophane)	10^7		γ, β	Spectrophotometer at 6,550 A (poor reproducibility)
		GAS SYSTEM				
Nitrous oxide	*Ha₂56*	Pure N_2O	3×10^9		β, γ, n	Measurement of pressure of $N_2 + O_2$ formed or colorimetric determination of NO_2 formed (at higher doses)

* The symbol ▶ indicates those methods that are most widely used.

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Absorption of Monoenergetic X- and γ-Rays

By MARVIN H. GREEN, *Department of Public Health, Philadelphia, Pennsylvania*

THE NOMOGRAM presented here is basically a graphic representation of the exponential equation $I = I_0 e^{-\mu T}$. Thus it is applicable not only to shielding problems but also to problems of radioactive decay (as indicated in the drawing below) and reactor neutron-flux change as a function of reactor period.

In addition to the exponential equation, the nomogram also uses the equation $T_{1/2} = 0.693/\mu$.

For the shielding case, the symbols represent the following quantities: I_0 = original intensity; I = intensity after filtration or absorption; μ = linear absorption coefficient; T = thickness of absorber; $T_{1/2}$ = half-value thickness.

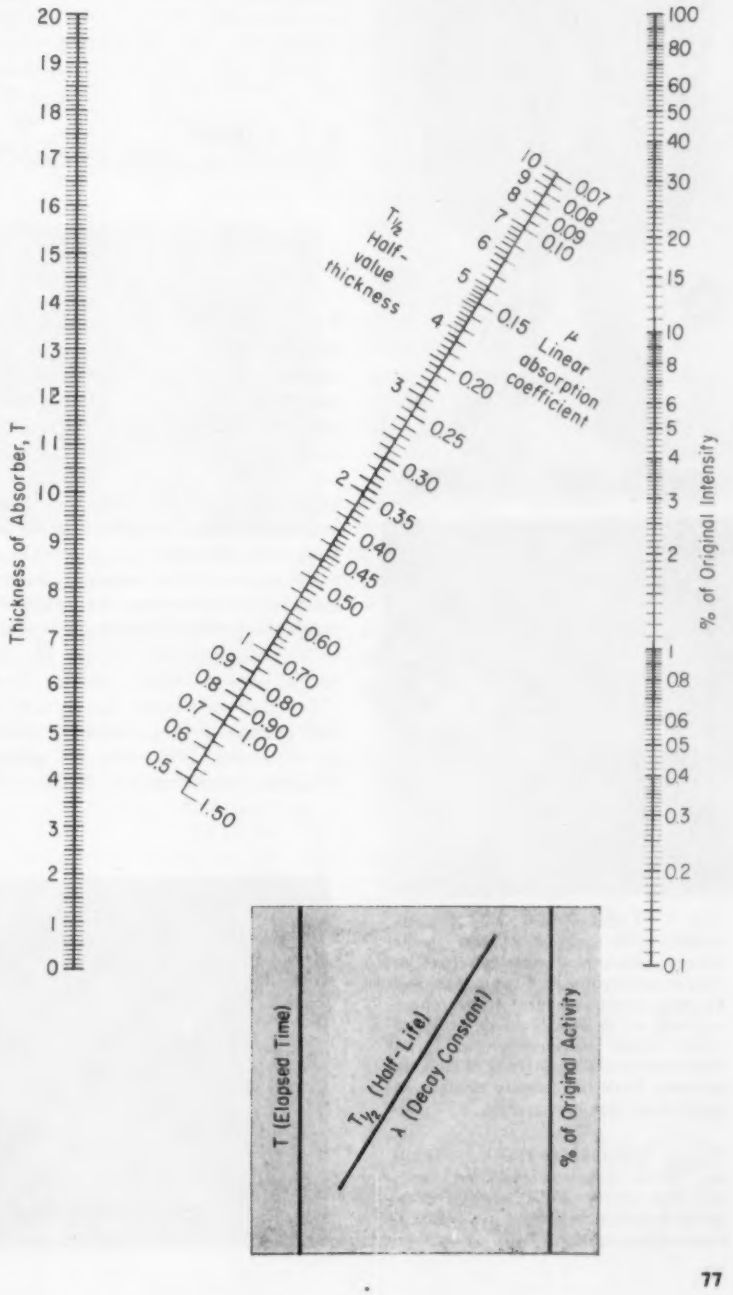
The inset below the nomogram indicates what parameters to use when applying the nomogram to radioactive decay.

The following examples illustrate the use of the nomogram:

Problem: What thickness of lead is needed to reduce intensity of 1-Mev γ-rays to 10% of original intensity? Given $\mu = 0.790$/cm.
Answer: Draw straight line from 10 on % scale through 0.790 on μ scale. Read 2.92 cm on T scale as answer.

Problem: Half-value thickness for 30-kev X-ray is given as 2.19 mm of aluminum. What % of original intensity will remain if X-ray is filtered by 4 mm of aluminum?
Answer: Draw straight line from 4 on T scale through 2.19 on $T_{1/2}$ scale. Read 28.3% on % scale as answer.

Problem: 7 mm of aluminum will reduce intensity of 40-kev X-ray to 32.2% of incident value. What is linear absorption coefficient in aluminum for X-ray?
Answer: Draw straight line from 7 on T scale to 32.2 on % scale. Read 0.162/mm as answer on μ scale.



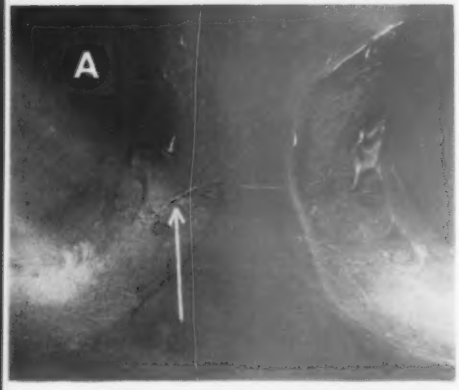


FIG. 1. CREEP-TESTED TO FAILURE, stainless-steel pressure vessel under internal pressure developed crack at nozzle penetration. Failure occurred because reinforcement at nozzle opening was not adequate to deter creep under stress concentration at joint. Data accumulated from tests of this kind provides basis for reliable analysis of structure at high temperature

Structural Design in

For very-high-temperature design, traditional stress analysis must be replaced with methods better suited to investigation of reactor structures subject to severe thermal stresses and progressive deformation with time

By N. H. TRINER
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FOR REASONS OF PERFORMANCE some nuclear-reactor systems are being designed and built for high-temperature operation. As a consequence, more attention is being focused on structural design for such conditions. The existing structural codes for pressure vessels, piping and heat exchangers are based on a large background of experience with structures that operate at temperatures where materials behave elastically. Structures for moderate-temperature reactors generally conform to existing practice, except for the special need to evaluate nuclear effects —i.e., thermal stresses due to neutron and gamma heating, radiation effects on mechanical properties, and greater reliability requirements. At the high temperatures involved in certain current and advanced applications, the standard codes lose some of the prestige of empiricism, and it has become necessary to review concepts that had not previously been challenged.

As a result of such critical reexamination, structural-design procedures are undergoing modification. The interesting point is that the approaches being developed for high-temperature structures are often more rational than the elastic methods they replace—rational, that is, in that the realities of material behavior are more adequately considered. Coded structural practice, based as it is on the assumption of elastic behavior, often masks the real response of the material by large factors of "safety." Aside from weight considerations, the thick members resulting from overconservative design incur, in a nuclear reactor, the penalty of excessive thermal stresses.

To achieve the balanced and efficient design required, one must define the response of materials and structures. This need has dictated that the basic tensile, fatigue and impact tests from which design properties are usually obtained be augmented by uniaxial- and biaxial-creep tests, high-temperature plastic-strain cycling tests, thermal-shock tests, relaxation tests and other specialized investigations (see Fig. 1). These data are pre-

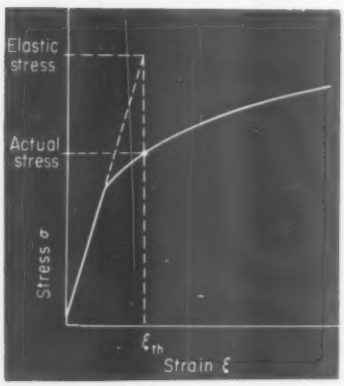

FIG. 2. STRESS FROM THERMAL STRAIN ϵ_{th}. Stress value was calculated assuming that elastic strain always overestimates actual stress because of relaxation and/or plastic strain

High-Temperature Reactors

requisite to the successful design of a high-performance elevated-temperature structure.

High-temperature structures differ most from normal practice in three aspects: (1) the existence of two types of stress, (2) effects of thermal stresses and (3) creep deformations.

Types of Stress

Stress is defined as the force per unit area developed within a part in response to its loading. There have always been two types of stress, but until recent years it was not important to distinguish between them in design.

Load stress. The least complicated stress situation is one in which the stress develops solely to resist a directly applied load. This is called a *load stress*. Two examples of load stresses are:

- A bar has a weight suspended from its end. Tensile stresses exist in the bar to maintain equilibrium with the applied load, and at any cross section of the bar the summation of stress equals the applied load.
- A thin-walled cylinder contains internal pressure. Here the membrane stresses, which hold the pressure forces in equilibrium, are load stresses. Their magnitudes depend only on the cylinder size and the pressure.

The identifying characteristic of a load stress is that it is determined solely from the equations of static equilibrium without regard to material behavior. These stresses are easy to calculate, and no conceptual difficulty is presented in predicting their effects.

Displacement stress. As soon as a material "constant" appears in a stress equation, the designer has encountered a *displacement stress*. This kind of stress results from a prescribed displacement imposed on the part rather than from a direct force. The identifying feature is that the stresses cannot be calculated without the introduction of some law of material behavior—such as Hooke's law or a stress-strain-time relationship. By way of illustration:

- A bar is clamped between two rigid walls, and the temperature is reduced uniformly. Standard elastic methods conceive the bar to be cut free at one end, allowing it to contract to its stress-free length, as dictated by the temperature drop and the expansion coefficient. The force necessary to stretch the bar back to its original clamped length can be determined from the known linear proportionality between stress and strain. The stress in the bar is $E \propto \Delta T$. This simplest of all thermal-stress problems is typical in that the basic ingredient is a prescribed displacement. The stress magnitude is dependent both upon this displacement and upon the stress response of the material to strain.

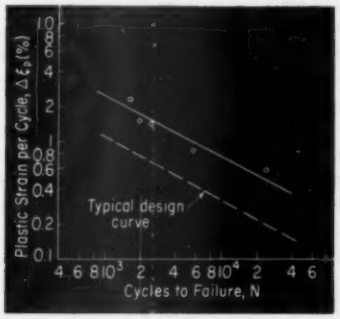

FIG. 3. THERMAL CYCLES TO FAILURE vs. plastic strain per cycle must be measured by experiment (circles). More conservative (dashed) curve would be used for design purposes. Data is for 316 stainless steel in argon at 1,500° F

- A cylinder under internal pressure has its end rigidly clamped (say by a heavy plate closure). Away from the end the cylinder expands radially, but the end cannot grow outward because of its attachment. Again the standard calculation calls for an imaginary cutting free of the end and the application of moment and shear to restore the end to its actual, fixed position. The stresses produced by these edge moments and shears are displacement stresses, for the magnitudes of the edge forces depend on the displacement and the stress response to strain.

At elevated temperatures the distinction between load and displacement stress is of more than academic interest: it is basic to design. When creep occurs, the bar that has a weight suspended from its end will grow with time and will continue to grow until it ruptures. This is the basic tensile-creep test, and it shows the effect of load stress.

Consider another bar stretched at high temperature to a prescribed length and then clamped. If the stretching is accomplished in a short time, the stress required to elongate the bar may be approximated by an elastic calculation, because appreciable creep has not yet occurred. This initial stress is high enough to cause creep growth, but after the initial stretching the bar was clamped and its length cannot change. The stress, then, must decrease with time—"relax"—from its initially high level to some lower level, if the length of the bar is to remain constant. The rate of decrease in stress depends upon the material and the temperature. The net result, after some elapsed time, is a low stress and a plastic strain that may be quite large. (However, if the bar does not rupture in the initial short-time stretching, it will not fail during the relaxation process.) This is a description of the creep-relaxation test and shows the effect of a displacement stress.

Thermal Stresses

Thermal stresses are displacement stresses. Hence any design involving thermal stresses must take into account the fundamental way in which they differ from load stresses. The relaxation process changes elastic strain to plastic strain by creep occurring within the framework of specified displacement. When this occurs the design variable changes from stress to plastic strain. Although failure of a ductile material will not occur under steady-state thermal stress, repeated cycling through this plastic strain can result in failure.

Owing to startup, shutdown and fluctuations in power demand, the thermal stresses (or thermal plastic strains) are cyclic in nature, and one must consider the implications of this thermal-strain cycling. Recently there

has been some outstanding research work on this topic by several investigators. The results of this work show that the failure criterion can be expressed as a limiting plastic strain per cycle.

To proceed from discussion of the qualitative effect of thermal stresses to design of the structure, it is necessary to determine strain magnitudes. For simple geometries it is rational to calculate thermal stresses elastically. Although such numbers are completely fictitious, they are used to obtain the associated thermal strains. This is done by applying the elastic constants to the fictitious stress values. This seemingly unsophisticated calculation is justified because we are dealing with displacement stresses. The deformations are imposed and stresses must follow in whatever way is possible from the characteristics of the material. To put it another way, thermal stress is the result of thermal strain. As shown in Fig. 2, the appropriate short-time stress-strain curve may frequently be used to find the upper limit of the thermal stress prior to relaxation.

One of the limitations of any simplified approach to the calculation of thermal strains is the existence of strain concentrations. Stress concentrations in normal elastic design are important because they serve as starting points for fatigue cracks. When creep occurs, relaxation leaves plastic strains in the wake of displacement stresses which are critical in the cycling situation. Concentrations of strain arise from many sources: notches and other geometric discontinuities, boundary conditions of restraint on members, material variations such as heat-affected zones adjacent to welds, and temperature gradients that lead to variations in properties.

The only way to determine the resistance of a material to failure by thermal-strain cycling is by experiment. Hence a test of this type is required to produce design data. In an effort to avoid some inherent shortcomings of thermal-strain cycling tests, one may rely on isothermal mechanical-strain cycling tests conducted at a temperature where effects are equivalent. Figure 3 is a plot of isothermal plastic-strain cycling data for type 316 stainless steel at 1,500° F, showing the margin that might be applied for design. In such a plot, N is the number of cycles to failure and $\Delta\epsilon_p$ is that portion of the total strain range that is plastic.

Thermal shock, or the problem of failure under a very small number of suddenly applied temperature-gradient changes, is of particular interest in dealing with brittle materials. Even a small capacity for plastic deformation causes the thermal-shock problem to approach the thermal-cycling situation mentioned above. In ductile materials, the rate of temperature change can be important because the thermal-strain magnitude depends upon this rate.

Figure 4a shows the temperature distribution through a wall as a function of time when the wall is in contact with a coolant having a low-resistance film, such as a liquid metal. Upon the application of a step change in coolant temperature, the surface temperature of the wall assumes the same value as the coolant temperature, which is markedly different from the volumetric average temperature of the wall. Since this temperature difference is the index of thermal-strain magnitude, it is not difficult to see that short-time plastic strains can result. For longer times after the shock the temperature disturbance penetrates the wall, changing the volumetric average temperature.

The design criterion for thermal transients, then, is to define a maximum tolerable strain for repeated cycling and to strike a balance between the rate of temperature change of the coolant and the thermal-response rate of the part. Figure 4b shows such a balance schematically.

Another aspect of thermal gradients, quite unrelated to thermal strains, involves changes in load-stress distribution caused by varying resistance to deformation. All the properties that determine this resistance to deformation are highly temperature-dependent. At high temperatures the stress distribution through a member subjected to a temperature gradient will be distorted—i.e., the hotter, more easily deformable portion will unload itself on the relatively stiff, cooler region.

Creep

At high temperatures creep becomes a major design consideration. "High temperature" is defined, for this discussion, as a temperature above which design stresses are determined by short-time properties. For example, conventional design may be based upon ¾ of the yield-point stress, but since materials do not respect the significance with which we endow their yield points, there is a temperature at which the yield stress causes the material to exceed a creep design limit (say ½ of the 10,000-hr rupture stress,

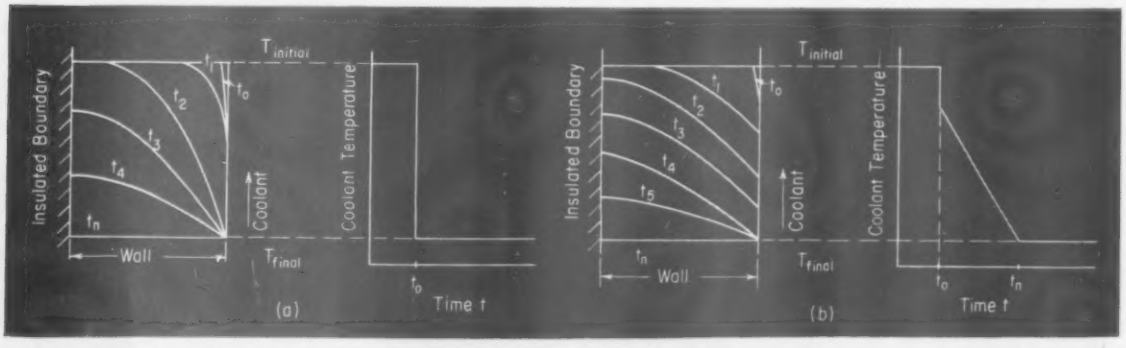

FIG. 4. THERMAL SHOCK suffered by wall (curves show temperature distribution for various times) when coolant temperature drops abruptly (a) is avoided (b) by programming coolant-temperature drop

or the stress that produces 1% strain in 100,000 hr). So, for some aluminum alloys, high temperature may be above 400° F; for a carbon steel, 900° F; for an austenitic stainless steel, 1,200° F; for a molybdenum alloy, perhaps 1,500° F.

Concerning stress analysis for creep conditions, much effort has been directed toward building a comprehensive mathematical mechanics of creep based on the tensile-creep curves. This would serve as the high-temperature counterpart of the well-known mechanics of deformable bodies which is based on the short-time stress-strain curve. In principle, this is feasible, and large strides have been made toward this objective.

Stress analysis of any structure consists in satisfying three conditions: equilibrium, geometry of strain (compatibility) and material behavior. Conceptually, to adapt the conventional mechanics of materials to creep conditions one need only replace Hooke's law, or some other representation of the stress-strain curve, with a mathematical relationship that defines the response of the material to load at high temperature.

Unfortunately, there is no simple relationship between stress, strain, time and temperature adequate to describe observed behavior. Whereas elastic strain is a linear function of stress, creep deformation is a complex relation composed of a power function of stress, an exponential function of temperature and a linear function of time—and even this is an idealization. It is often possible to derive the nonlinear partial differential equation that governs the stress and strain distribution of a component, but the inadequacy of mathematics precludes the solution of the equations in most cases.

This mathematical obstacle has put the task of evolving a comprehensive creep mechanics in the realm of research and has led design and development engineers to invent analytical substitutes for the more rigorous classical approach. One such substitute that has been successful in the solution of creep-buckling and creep-shell-deformation and stress-distribution problems replots the tensile-creep data as isochronous stress-strain curves. (Creep data are normally presented as strain-time plots with stress and time as parameters, whereas the "iso" curves are on stress-strain coordinates with time and temperature as parameters, as shown in Fig. 5.) The working curves for creep are now analogous to the familiar stress-strain curve. The procedure of analysis is to use the iso curve representing behavior at a particular instant of time t_i to obtain a time-independent solution for that instant. With the state of stress and strain known at time t_i, the process is repeated for the next instant of time t_{i+1} by using the next iso curve to account for the change in material behavior during the time interval.

Optimum design of a structure under creep conditions is attained when all parts of the structure deform at the same rate. In any practical structure, however, this cannot be achieved. One of the major reasons is the existence of displacement stresses in regions such as pressure-vessel closures and nozzle reinforcements. As mentioned above, such stresses tend to relax, leaving behind plastic strains. Although these strains are not cyclic, they are possible trouble spots. Certain combined stress ratios lead to limited fracture ductility; every effort is made to eliminate strain concentrations in regions where such ratios exist. Figure 1 shows a small pressure vessel creep-tested under internal pressure. The failure, shown in the inset, was predictable from the design creep data. This rupture happened because of inadequate reinforcement of the nozzle cutouts.

Creep deformation is very sensitive to temperature, applied stress and metallurgical variables. This sensitivity requires careful control of test conditions and specimens. The absence of such control leads to excessive scatter of materials data, with consequent uncertainty in the prediction of structural performance. However, there is ample evidence that adequate control of conditions and material leads to very reproducible creep data. Further, in the experience of many workers, when control is maintained, structural behavior is, indeed, predictable from analysis.

The need for control of test conditions and test materials in obtaining consistent mechanical-properties data implies a related need for careful acceptance testing of the actual construction material.

One must look ahead to the day when construction material must be checked to ensure that it is, in fact, equivalent to the material from which the design data were obtained. If the reactor is to have a 5,000-hr life, the 5,000-hr properties were probably verified experimentally, but this cannot be done for a load of metal arriving at the receiving platform. One must devise short-time acceptance tests for this purpose which have been verified through correlations with long-time tests over a wide range of variables.

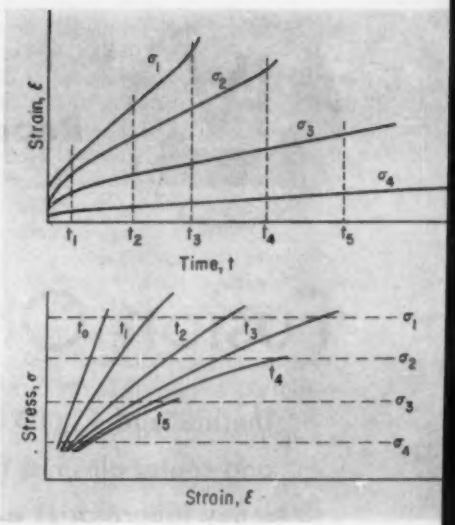

FIG. 5. CREEP-TEST RESULTS of strain vs. time for constant stress (above) become more convenient to stress analyst when replotted as stress vs. strain at different times

Conclusions

There is a rapidly expanding background of experience with high-temperature structures. The incentive to improve performance by raising working temperatures has spurred tremendous activity in the field. Experience and knowledge have advanced to the point where a high-performance project may be undertaken with confidence that a suitable elevated-temperature structure can be developed. However, this development is based upon directly applicable materials data and thorough engineering—it is not a handbook procedure.

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Report on the Uppsala Conference

Fusion One Year After Geneva

Thermalized 13,000,000° K plasmas held for 2 μsec are claimed in Scylla and cooler plasmas for about five times as long in NRL's theta pinches. Many laboratories are eagerly pursuing this and other leads, but fusion power is still a long way off, though our understanding of plasma physics is growing

By STIRLING A. COLGATE, *Lawrence Radiation Laboratory, University of California, Livermore, California*

THE SUPERBLY MANAGED Fourth International Conference on Ionization Phenomena in Gases held in Uppsala, Sweden, August 17–21, was large—over 500 scientists from 25 nations, but it was intimate and simple in comparison with the marathon of Geneva almost a year ago. To those of us more concerned with the plasma physics of fusion, the opportunity to concentrate our effort upon the newer theories and most recent experiments was a welcome relief from the exhausting repetition of the broad programmatic description of a year ago.

It is more than superficially important that plasma physics rather than machine programs be discussed. For at every turn plasma phenomena have proved to be more intricate than our theories and experiments anticipated. There is a clear need for much better understanding of the basic phenomena.

It may be desirable therefore to dispense at the outset with questions about fusion *power*. It is, as has been said so often in the past two years, still a long way off. The theta-pinch devices which attracted so much attention at the Uppsala meeting are important for the physics they reveal, but they fail by a factor of 1,000 to provide sufficient confinement time to be of interest for thermonuclear power production. However, the vigor of plasma researchers and the richness of plasma phenomena lends hope that someday that goal will be reached.

Theta Pinches

The conference topic that aroused greatest interest was the theta pinch. This is a fast axial-magnetic-field compression of a shocked-heat plasma in which the induced current flows in a circle (theta direction) about the axis of the discharge tube. Thus the theta pinch differs from the classical linear pinch in that the directions of magnetic field and discharge current are interchanged.

A typical theta-pinch device consists of an axial field coil, usually single or fractional turn, wrapped around a sturdy insulating tube, usually quartz or alumina. A fast and powerful capacitor bank is discharged into the coil and the resulting fast-rising axial field induces a current in an initial gas discharge (usually deuterium at about 100 microns pressure) ionizing and driving the plasma rapidly towards the axis of the tube. The objective is the achievement of high plasma temperature by both the initial shock heating and subsequently by the adiabatic compression of the plasma. Neutron production is observed usually in the second half-cycle of capacitor discharge—with perhaps small neutron bursts being observed early in later half-cycles.

There were seven different independent papers presented on this topic (see table) and each has a bearing upon the fundamental question, namely, what is the method of heating and does this result in an approximately thermal distribution. (Nonthermal distributions—dominated by a few highly energetic particles—are less instructive of fundamental plasma behavior.) Three of the theta-pinch-experiment papers will be discussed here, along with some of the theoretical insights into the behavior of such systems.

Naval Research Lab. The scientific paper by Alan Kolb on his theta-pinch experiments at the Naval Research Laboratory did not claim a proven thermonuclear reaction but instead discussed the experiments that admitted of this possibility.

A major point of Kolb's experiment was the demonstration that neutron production is correlated with the presence of a reversed trapped magnetic field with the current flowing within the plasma at the layer bounding the reversed field. In Kolb's experiment an initial reversed field introduced slowly before the rise of the main field caused the production of neutrons when in the reversed direction to the main field and caused no neutrons when aiding the main field, in accordance with

the original prediction and suggestion of Harold Furth.

The importance of the reversed-field trapping* was emphasized in all the subsequent papers. The rapid disappearance of reversed field after the plasma was partially compressed was usually associated with sudden plasma heating. After this heating, the relatively long rise time of Kolb's experiment demonstrated mirror confinement for about 8 μsec, limited by collisions that permitted the plasma to leak out the ends.

Los Alamos. James Tuck reported on the Los Alamos theta-pinch experiments conducted with Scylla (NU, Sept. '58, p. 69). Based on very extensive measurements Tuck said that it was his opinion that their theta pinch was most probably thermonuclear, i.e.: the ions were substantially in thermal equilibrium.

The observation of X-rays in both the NRL and Los Alamos theta pinches was confirmatory evidence of a high temperature, but the X-ray evidence of Los Alamos gave $T \cong 200$ ev (2,000,000° K). The ion temperature at Los Alamos was claimed to be 1.3 kev (13,000,000° K) by excellent doppler-broadening measurements of reaction products parallel to the axis. (The fact that the electron temperature is lower than the ion temperature is not surprising—it is to be expected for most heating mechanisms.)

Strong evidence for the thermal equilibrium in the Los Alamos experiments is provided by the smallness (less than a few hundred ev) of the doppler shift in the neutron emission normal to the axis of Scylla. Ribe and Tuck claim that their temperature is consistent with solely shock heating and adiabatic compression. The Los Alamos group has not done the reversed-magnetic-field experiment despite the production of neutrons only during the second half-cycle. However the time-history symmetry and uniformity of neutron production at Los Alamos indicated a possibly different process than characterized by the neutron bursts of other theta pinches.

Theta Mechanisms

The first study of a plasma current layer, separating two regions of oppositely directed magnetic field was made by Anderson, Baker, et. al., on the triaxial or tubular pinch. In this configuration a current layer is maintained between opposite azimuthal magnetic fields for a protracted length of time, ~3 μsec. The origin of the observed neutron emission has been difficult to explain on the basis of an equilibrium, thermal plasma despite the isotropy (lack of doppler shift) in the neutron emission. The observed electrical resistivity is inconsistently high in view of the high required plasma temperature, and has been suggestive of phenomena such as instabilities and turbulence.

The first-order similarity of the tubular pinch current layer with a possible reverse-field current layer in the theta pinch led Furth to suggest that a reverse-field current layer might be responsible for neutron generation in the theta-pinch experiments. The fact that such a correlation was then observed by Kolb has stimulated a search for a better understanding of the phenomenon involved.

The presence of an instability in the theta pinch is not open to doubt, because in all experiments presented at Uppsala the reversed trapped field disappears far more rapidly than thermal equilibrium would permit. In particular the experiments described by Samain of the French AEC clearly

* Those unfamiliar with the physics of plasmas may find the concept of reversed trapped fields somewhat startling. The important thing to bear in mind is that plasmas have very high conductivity and currents can flow in relatively thin layers of plasma sufficient to account for a discontinuity in magnetic field direction on either side of the plasma layer. Pulsed oscillatory currents are generally used to establish the magnetic fields in pinch experiments; under the right circumstances the magnetic field in one direction that is established by the first half-cycle of current is trapped and compressed within the plasma and succeeded by a reversed magnetic field generated by the reversed current of the second half-cycle.

Seven Laboratories Report on Theta Pinches

Laboratory	Authors	Coil dimensions (cm)		Peak field (kilogauss)	Rise time (μsec)	Mirrors?	Remarks
		Diameter	Length				
Los Alamos	Tuck, Ribe	4	10	50	2	yes	Doppler shift, neutron and X-ray measurements
Naval Research Lab	Kolb, Griem	5	30	70	5	yes	Reversed-field trapping, neutrons and X-rays
Fontenay-aux Roses, France	Samain	20	20	6	5	yes	Visual framing picture of instability breakup
Rome	Segré, Alan	10	20	2	9	no	Pictures of argon shocks
Aachen, Germany	Jordan, Fay	2	10	50	1	yes	Trapped reversed-field neutron correlations. Probe measurements
Aldermaston, England	Bodin, Niblett	5	20	100	2	no	Excellent streak photo of reversed-trapped-field-disappearances instability
Moscow	Kvartshava	10	40	20	8	no	Streak photos of reversed-field breakup, no neutrons (H_2 gas)

documented just such an instability. The current layer separating the reversed trapped fields is similar to an ordinary nonstabilized toroidal pinch and is subject to the same kink and sausage instabilities.

The similarity of the tubular pinch and reverse-field theta pinch should not imply a complete similarity in the origin of the neutrons. The reason for this is that the tubular pinch starts and remains as an unstable configuration, whereas the reverse-field theta pinch relaxes to a possibly stable configuration, namely a high-pressure plasma in a unidirectional mirror field. The instabilities in both cases may lead to high-energy accelerated particles, but in the theta pinch these accelerated particles can be contained and may relax to a thermal distribution.

We thus see emerging the possibility of utilizing an instability to give the sudden heating required to reach high temperature, while at the same time creating a stable confinement geometry.

Russian Work

Nineteen Russian papers were presented to Conference Secretary Åke Nilsson, two days before the beginning of the conference. The rest of the world had abided by the June deadline for abstracts, so that the arrangement of the schedule and the printing of meaningful summaries could take place before the opening session. I am sure the Soviet scientists were as embarrassed at the imposition as was Dr. Nilsson at rearranging the schedule. The Soviets were equally covetous in excluding meaningful content from their Geneva abstracts. It would seem that the time has arrived for Soviet bureaucracy to give way to the not-unreasonable demands of scientific exchange at international conferences.

As usual the Soviet papers were extremely competent and interesting.

Joffe's measurements of the decay time of mirror-confined plasmas produced by the ion-magnetron technique gave indications of an enhanced loss rate that is not evidently associated with the better-understood nonadiabatic effects, but was extremely sensitive to the magnitude of the field. Localization in velocity space is suspected, but not proved.

Sinelnikov gave an extremely interesting survey of the work at his institute in the Ukraine where one of the most striking innovations was the injection of electrons into a mirror field where the central part of the mirror field was rippled in space. In the frame of the axial velocity of the injected electron the spatial variation was in resonance with the electron cyclotron frequency. The resulting nonadiabatic change in the electron magnetic moment of at least 50% permitted trapping for about 1,000 reflections.

Sagdeyev of Moscow gave a particularly brilliant paper on shock-wave structure in which he showed that for a collisionless weak shock with a magnetic field a certain group of ions would be multiply reflected from the "moving potential" hill at the front and be accelerated to extremely high energies (with velocity equal to the electron velocity). This represented one more method (aside from instabilities) of obtaining very-high-energy if nonthermal particles in a plasma.

Axial Pinches

The investigation for the so-called stabilized pinch of stability and energy loss still dominates much of fusion work, with effort at Fontenay-aux-Roses, A.E.I. Aldermaston, Harwell, Uppsala, Moscow, Germany, and Los Alamos. But despite some measurements to the contrary there still remains an unexplained energy loss during the initial part of the cycle which is over and above impurity radiation in the form of ultraviolet light. Some measurements presented by Furth of Livermore showed a marked difference from instability to stability measured by magnetic probes for some of the hard-core (central metal rods) pinches. The observed stability was hopeful for the future of the pinch.

There was considerable interest in accelerated plasma in various geometries—principally coaxial, with some emphasis on efficiency of acceleration—as if someone were going to take off to Mars. But more seriously Marshal's work at Los Alamos has shown 30% efficiency for accelerating a puff of gas into a vacuum. Similar efficiencies are obtained in Dattner's work at Stockholm, Patrick's at Avco and Komelkov's at Moscow, but in the latter cases a shock is accelerated into cold gas so that the possibilities of new experiments are somewhat more limited. It should be pointed out that the efficiency of some dynamic pinches when the first bounce occurs at current maximum and when the series inductance is small is considerably greater than 50% for the conversion of electromagnetic energy into kinetic energy.

Future Plans

During the course of the conference various future plans were discussed, and some in great detail, which indeed is a gesture of good faith in the future.

Dick Post of Livermore described the plans for the Alice experiment at Livermore in which he plans to inject a neutral atomic beam of ½ amp and 10–20 kev into a mirror field of 50 kilogauss. This is an ambitious undertaking but smaller in almost all respects than the Ogra or DCX experiments.

Niblett of Aldermaston described the Phoenix experiment (plasma heating obtained by neutral injection experiment!!) the title of which caused so much laughter that it is somewhat vague what it does—but they do have plans for an extremely large (a few $\times$ 10^6 joules) and fast ($\sim$1 μsec) condenser bank for fast pinch work both theta and axial.

Chick at A.E.I. described a new but extremely accurate pinch torus that will soon be in operation of about 12" minor diameter and carefully uniform aperture.

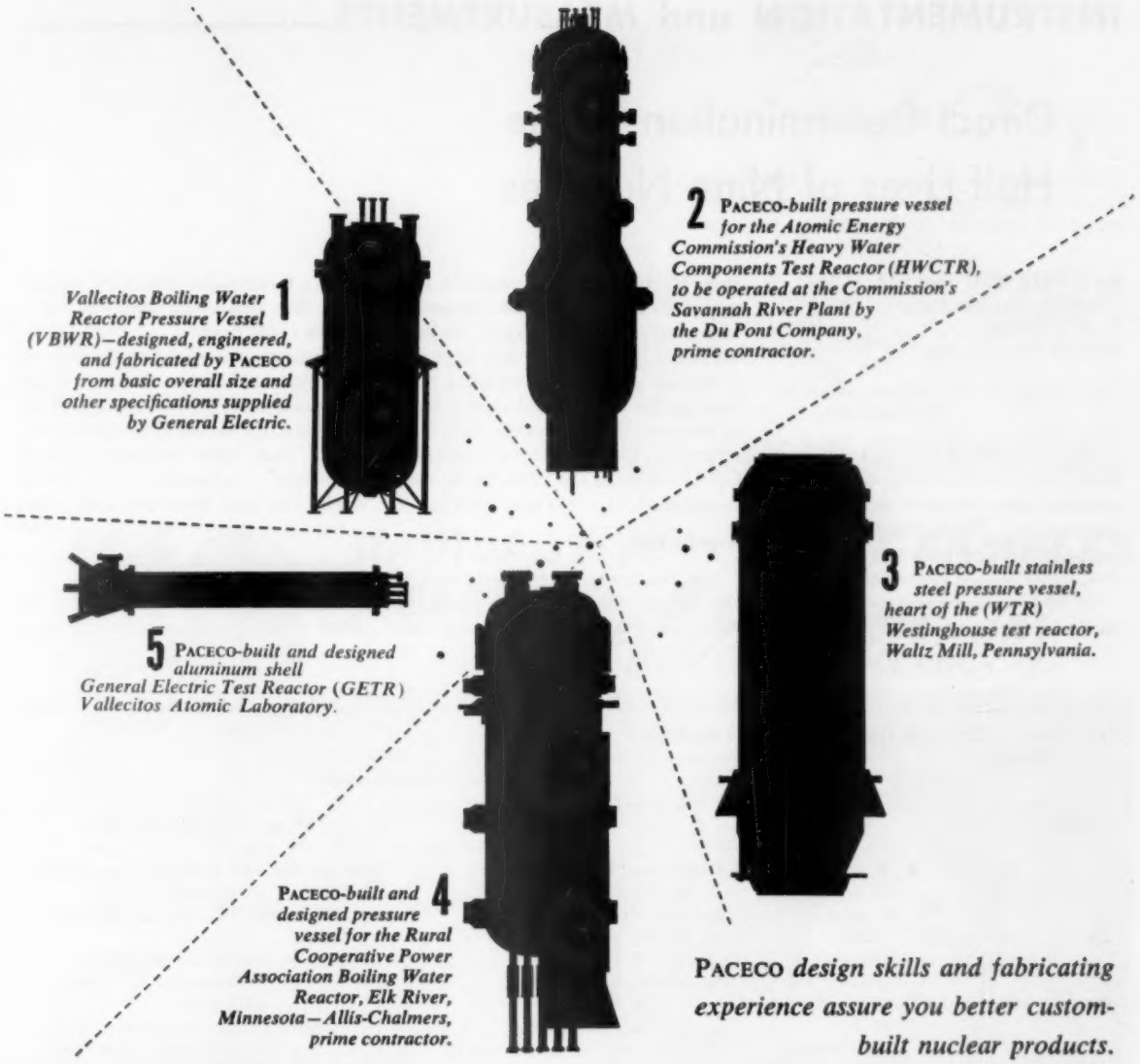
Francis of Harwell described the ICSE experiment which will be a larger torus to replace Zeta—the rationale being that greater energy and higher particle density will prevent disastrous runaway electrons.

Tuck at Los Alamos plans to inject into cusp geometry by boring a hole with plasma pressure and then by expansion of the plasma inside allow the hole close to off (entropy trapping).

Lehnert at Stockholm described his current ring—1 million amperes fed by d-c current leads—which, coupled with a toroidal field, should give a highly stable confining magnetic field with large shear.

Colgate described plans for a similar device—the Levitron where the current is induced in a shorted ring (no leads) threading a torus. The ring is "levitated" by pulsed a-c fields.

The future plan that was unanimously greeted with greatest applause as having the highest probability of succeeding was the announcement by Paul Schulz of Hertestor, that the Fifth International Conference on Ionization Phenomena in Gases will take place in Germany in 1961.



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Direct Determination of the Half-Lives of Nine Nuclides

By J. PAUL CALI and L. F. LOWE
Cambridge Research Center
U. S. Air Force
Bedford, Massachusetts

The half-lives of nine isotopes have been newly determined by direct measurement after extensive radiochemical purification. These values are compared in the table with previous values frequently quoted in the literature.

In work involving neutron-activation analysis, the accuracy of the half-life value is important when using the activation equation to calculate the results of an analysis. The value of the half-life enters into the saturation term and is also needed to correct counting rates back to the end of irradiation. Since at least two different values have been reported in the literature for each of the isotopes listed in the table, the new determinations reported here were made.

Irradiation

The irradiations were performed in the target conveyor system of the Brookhaven National Laboratory reactor at a thermal flux of 8×10^{12} n/sec/cm^2. The irradiation time was 2.6×10^6 sec (~30 days).

For those elements where the induced activities could lead to confusion in the measurement of the desired half-lives, separated stable isotopes were irradiated. These were calcium-44 (98% enriched), ruthenium-102 (94% enriched) and hafnium-180 (93% enriched).

Radiochemical Purity

To ensure radiochemical purity, extensive chemical procedures were used

New Determinations of Half-Lives of Nine Nuclides

Nuclides	*New half-life values*	*Previous half-life determinations*		
		Half-lives	*References*	*Remarks on previous values*
S^{35}	88.8 ± 1.0 d	87.1 ± 1.2 d	*J. Phys. Chem.* **47,** 469 (1943)	Low activity; no chemistry mentioned
		88 ± 3 d	*Phys. Rev.* **60,** 537 (1941)	9 months on electroscope
		87.16 ± 0.1 d	*J. Research NBS* **60,** 447 (1958)	4π beta counter; followed for 5 months
Ca^{45}	167 ± 3 d	152 d	*Phys. Rev.* **72,** 163A (1947)	No details
		180 ± 10 d	*Phys. Rev.* **57,** 177 (1940)	Electroscope; chemical purification
		163.5 ± 4 d	*Phys. Rev.* **89,** 529 (1953)	No chemistry; followed for 202 days
Ru^{103}	39.4 ± 0.4 d	39.8 ± 0.4 d	*Phys. Rev.* **79,** 891 (1950)	Purified Ru metal used
		45 d	*Phys. Rev.* **74,** 1536 (1948)	No chemical purification mentioned
		39.7 ± 0.6 d	*Nuclear Sci and Eng.* **2,** 427 (1957)	Chem. puri.; followed for 3.4 half-lives
Ag^{110m}	262 ± 5 d	225 ± 20 d	*Phys. Rev.* **54,** 88 (1938)	No purification; followed for 1 yr
		282 d	*Phys. Rev.* **79,** 237 (1950)	No purification mentioned
		252.5 ± 1.5 d	*Phys. Rev.* **105,** 1539 (1957)	No chemistry; ion chamber used; followed for 2 half-lives
		253 ± 4 d	*Bull. soc. roy. sci. liège* **26,** 29 (1957)	No chemistry; followed for 90 days
In^{114m}	50.1 ± 0.3 d	48.5 ± 2 d	*Phys. Rev.* **56,** 414 (1939)	Some chem. purification; ion chamber
		50 d	*Phys. Rev.* **57,** 982 (1940)	No chemistry
		50.0 ± 0.3 d	*Nuclear Sci. and Eng.* **2,** 427 (1957)	Chem. puri.; followed for 5.3 half-lives
Sb^{124}	60.1 ± 0.3 d	60 d	*Phys. Rev.* **55,** 414 (1939)	n,α on I^{127}; no chemistry mentioned
		59.9 ± 0.5 d	*Phys. Rev.* **109,** 1243 (1958)	No chemistry
		60.9 ± 0.2 d	*Nuclear Sci. and Eng.* **2,** 427 (1957)	No chemistry; followed for 2.5 half-lives
Pm^{147}	2.7 ± 0.1 yr	3.7 yr	NNES 9* Paper 190 (1951)	Early work on rare-earth fission products
		4 yr	NNES 9* Paper 192 (1951)	Calculated from fission yield of Nd^{147}
		2.66 ± 0.02 yr	*J. Inorg. & Nuclear Chem.* **3,** 160 (1957)	Purified chemically; followed for 1.8 yr
		2.64 ± 0.02 yr	*Can. J. Phys.* **35,** 16 (1957)	Purified chemically; long storage of fission products
Hf^{181}	45.5 ± 0.3 d	45 d	*Phys. Rev.* **78,** 299 (1950)	No chemistry; 5 half-lives followed
		47 d	*Arkiv Mat. Astron. Fysik* **35A,** 35	No chemistry mentioned
Hg^{203}	47.2 ± 0.7 d	43.5 ± 0.5 d	*Phys. Rev.* **74,** 849 (1948)	No chemical purification mentioned
		47.9 ± 0 2 d	*Phys. Rev.* **85,** 386 (1952)	Enriched isotope used; no chemistry
		45 ± 0.5 d	*Nuclear Sci. and Eng.* **2,** 427 (1957)	Purified chemically; followed 4 half-lives
		47.1 ± 0.2 d	*Bull. soc. roy. sci. liège* **26,** 29 (1957)	No chemistry; followed for 105 days

* NNES 9 = National Nuclear Energy Series, vol. IV-9 (McGraw-Hill Book Co., New York).

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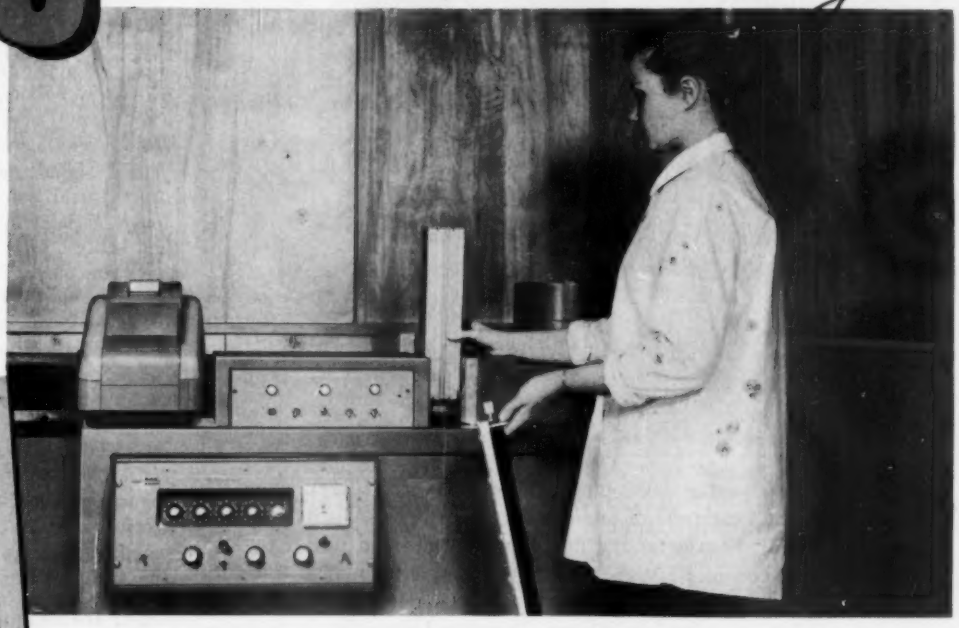

31	21.12	N	
32	3.41	N	
33	3.34	N	
34	2.38	N	
35	2.47	N	
36	36.67	B	
37	2.72	N	
38	.67	N	
38		L	
1	34.72	B	
2	3.54	N	
3	3.02	N	
4	24.65	T	
5	.96	N	
6	1.20	N	
7	5.81	N	
8	2.23	N	
9	1.46	N	
10	35.49	B	

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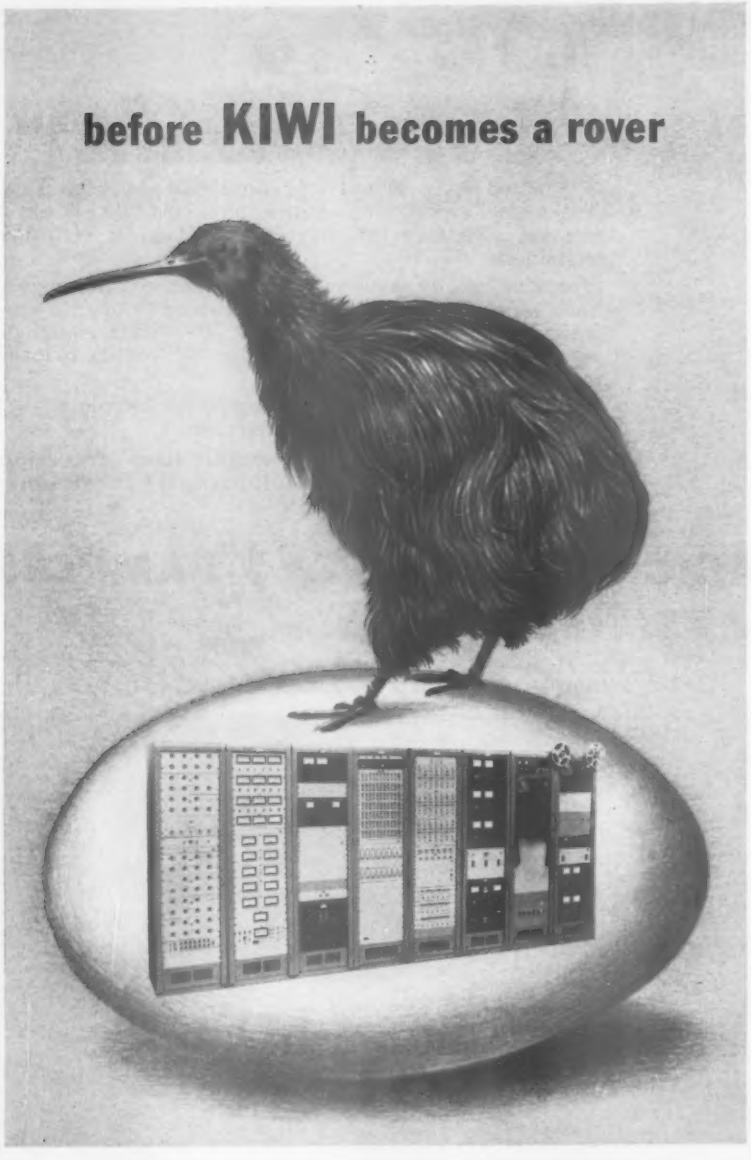

Project Rover is aimed at developing a nuclear-powered rocket engine that will result in man's conquest of intergalactic space. Kiwi-A is its first land-based test reactor, named for the flightless New Zealand bird.

Before Kiwi becomes a space rover, an immense amount of test information will be needed. Edgerton, Germeshausen & Grier, Inc., is cooperating with the AEC, NASA and Los Alamos Scientific Laboratory in collection of this vital data.

For Project Rover, EG&G has designed, built and is now operating an 800-channel control and instrumentation system yielding diagnostic information for designers of tomorrow's spacecraft.

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for each of the elements after its irradiation.

In general, the following techniques were employed: dissolution in an appropriate solvent; removal of neighboring activities by the addition of $Z + 1$ and $Z - 1$ carriers and chemical separation from the wanted Z element; scavenging of trace impurities on gelatinous precipitates, such as ferric hydroxide; selective precipitation and/or solvent extraction and/or distillation of the wanted element from impurities, especially those of the same periodic group; and, finally, the precipitation of a stable form or compound of the element to be measured.

Counting Procedure

After the radiochemical purification, the various elements were mounted on aluminum planchets with collodion-ether. When the ether had evaporated, a film of rubber hydrochloride was placed over the planchet and held with a retaining ring. The assembly was dried under vacuum and stored in a desiccator, being removed only for counting.

The samples were counted in a modified Los Alamos–designed methane-flow proportional counter. The window was a Mylar film (aluminum-coated), and the geometry was approximately 2π. The counter had a 200-volt plateau at 4,600 volts.

Samples were run in duplicate and counted periodically to a total of 2^{16} counts per sample. Variations in the counter and its associated electronic equipment were eliminated by normalizing all data with a long-lived standard source (U^{238}-Th^{234}-Pa^{234}, commonly known as a UX-2 source). The extreme variation of the UX-2 source counting rate was less than 4% during the twenty months of these experiments.

Data Treatment

Plots of the log counting rate versus time were made to determine visually any variation from a straight line. From 12 to 20 points were available for the least-squares calculations (6 points for Pm^{147}) and covered from 2 to 6 half-life intervals (silver-110 and promethium-147 covered 1 and ½ intervals, respectively).

The error of the reported values is based on the standard deviation of the slope of the log count versus time line and consequently is the standard error.

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* * *

Acetylacetonate derivatives of the transition metals (for example, chromium, cobalt, manganese, vanadium, iron, and nickel) have recently been made available in research quantities by Union Carbide Metals. These "Electromet" acetylacetonate compounds provide a convenient means of putting the metals in solution in organic systems; the compounds are chelated, non-ionizing substances, slightly soluble in water. They form solutions which are neutral and resistant to hydrolysis. The acetylacetonates are available in the form of pure, crystalline powders of medium bulk density. Bulletin AA1-N3 gives details.

* * *

Time-saving mixes, having proved their worth in the kitchen, have now moved into the metallurgical field. Examples of this concept are Union Carbide Metals' more than 15 titanium alloy addition agents. The first of these was 85% vanadium-aluminum, developed in 1954 to expedite commercial production of the high-strength 60% aluminum-40% vanadium alloy. The list now includes a tantalum-columbium-aluminum combination for the new 8-8-1 alloy. Data Sheet AT1-N3.

* * *

Among the Union Carbide Metals family of oxides are columbium and tantalum oxides. Both have high dielectric constants useful in electronics. Columbium oxide is also an intermediate material for producing compounds with great hardness and high melting point. Tantalum oxide is a source for tantalum carbide, a cutting tool additive which increases resistance to abrasion and oxidation. Send for Data Sheet OX1-N3.

* * *

Substantially improved specifications for vanadium metal, particularly as regards gaseous impurities, have been announced by Union Carbide Metals Company. Through the use of improved production methods, hydrogen content has been cut by 90 per cent and nitrogen and carbon contents by 50 per cent. Analyses of 500- and 1000-pound lots show that the sum of carbon, oxygen, hydrogen, and nitrogen is in the range of 0.1 per cent. Write for Bulletin VM1-N3.

* * *

Stainless steel shapes of more than 95 per cent theoretical density have been made from Union Carbide Metals' new stainless steel powder. The composition of the powder is similar to Type 316 or CF-Mo alloys. Mechanical properties of the sintered shapes closely approach those of wrought shapes. Union Carbide Metals field consultants, working with metal powder fabricators, are developing the promising potential for this stainless steel powder in many uses, including gears, bushings, and other shapes exposed to aggressive corrosion environments. Data Sheet SS1-N3 gives additional information.

* * *

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FIG. 1. EXPERIMENTAL ultrasonic tester for unbonded areas under cladding of uranium slugs

Instrument Development at Savannah River—I

Nondestructive-Testing Equipment

By J. N. WILSON, *E. I. du Pont de Nemours & Company*
Savannah River Laboratory, Aiken, South Carolina

This first article in the series on Savannah River instrumentation is confined to instruments used for pre-operational testing of reactor fuel and control components. Parts II and III will be concerned with reactor, fuel-processing and health-physics instrumentation.

The problems that can result from the failure of fuel elements or other components require exhaustive testing of all such pieces prior to their use in reactors. Normal quality-control methods are not sufficient since even one faulty piece out of thousands may result in a costly shutdown. It has been necessary to develop nondestructive testers (*1*, *2*), often using ultrasonics, eddy currents or penetrating radiation. Commercially available instruments that meet test requirements in principle are often designed to be quite versatile; consequently, they may be too complex to be usable under industrial plant conditions or may require highly skilled data interpretation. The Savannah River designs are simple, single-purpose instruments that are easy to operate and maintain.

Ultrasonic Testers

Good thermal contact must be maintained between uranium fuel and its cladding—the best thermal contact is provided by a continuous metallic bond. Since heat and sound are conducted by the same mechanism, a satisfactory test for the detection of nonbonded areas is provided by measuring the attenuation

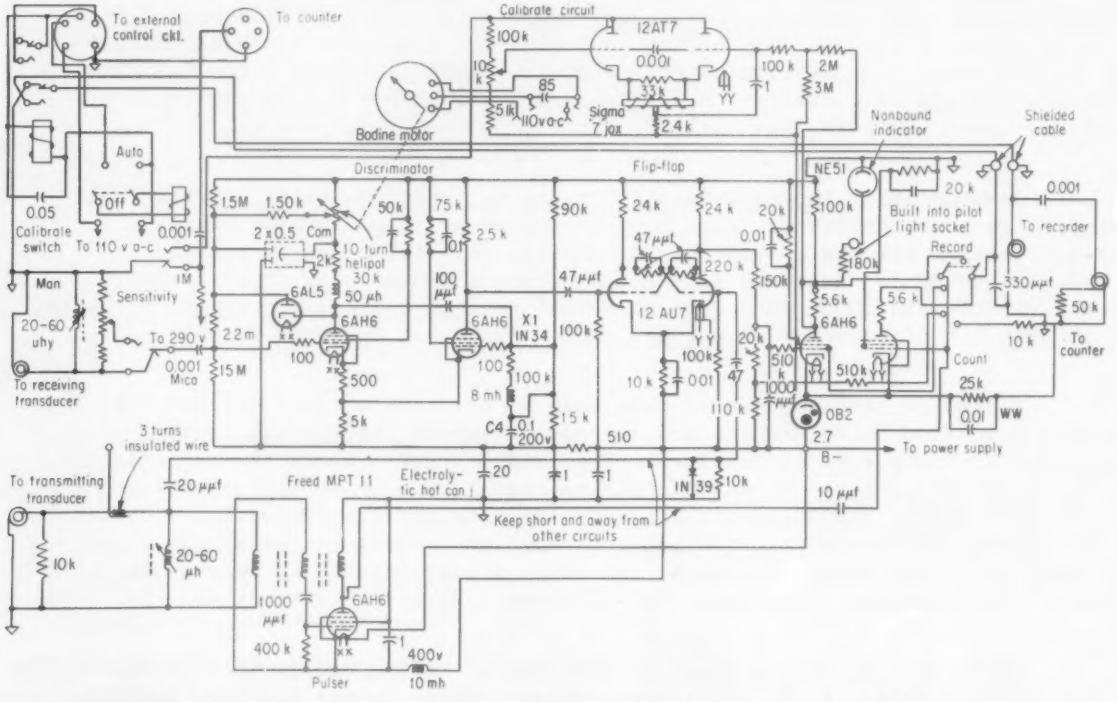

FIG. 2. ULTRASONIC BOND TESTER circuit; power supply is not included. Complete circuit uses only ten tubes

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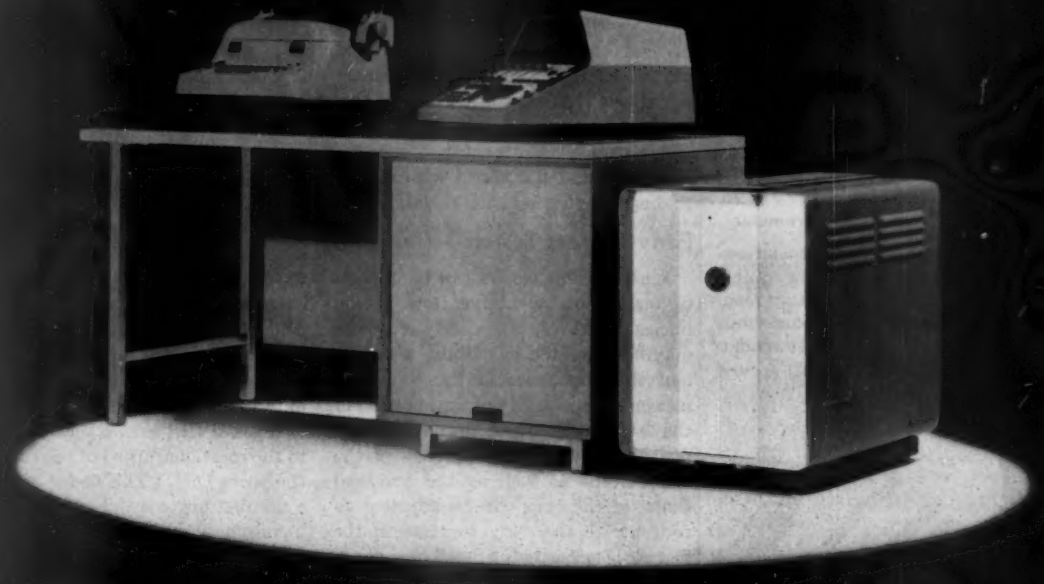

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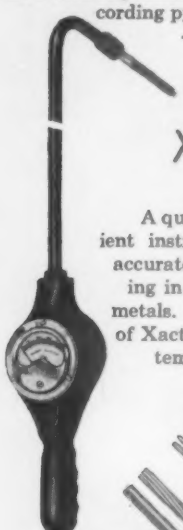

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This article starts on page 90

of an ultrasonic beam across a diameter of a fuel slug.

The latest Savannah River circuit (*3–5*) uses barium titanate transducers and can be read out with a mapper, a scaler or a simple discriminator reject mechanism. Earlier circuits utilized quartz crystals (*6*), which required high voltages and sensitive amplifiers.

Figure 1 shows a complete laboratory ultrasonic tester. The transducers are coupled to the slug by the water bath. The circuit is shown in Fig. 2 (*5*). A unique feature is the automatic self-calibrator, which corrects for temperature changes and buildup of algae at the transducers. The absence of a slug between the transducers is detected by switches that turn on the calibrator. The calibrator circuit introduces a fixed attenuator in the receiving-transducer signal lead that has the same effect as a nonbonded slug. A small servomotor automatically adjusts the discriminator level to sound the alarm with signals that equal or are less than this standard.

Eddy-Current Testers

Eddy-current testers can be applied to many nondestructive tests in the nuclear field (*1, 2*). Eddy currents may be generated by suitable a-c coils, and the impedance of the coils is a measure of resistivity of that portion of the test piece in which the currents are made to flow. The frequency of the coil current as well as the size and shape of the coils can be adjusted to concentrate the eddy currents in the test piece as desired. Small changes in apparent resistivity can disclose the presence of cracks (*7*), intergranular corrosion (*1, 8, 9*), alloy penetrations (*10–12*) and surface blemishes (*13*), or they can permit cladding- and plating-thickness measurements (*14–16*).

The automatic tester shown in Fig. 3

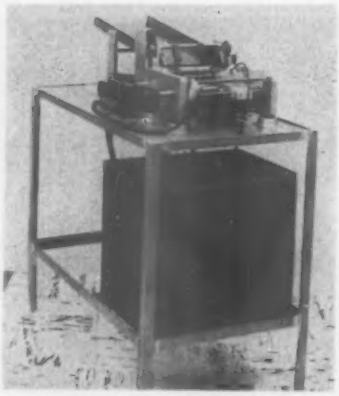

FIG. 3. EDDY-CURRENT FUEL-CAN TESTER. Probe of experimental unit scans surface of rotating slug can for cracks and inclusions

is a laboratory model of an eddy-current tester for the aluminum cans used to cover uranium slugs. The probe and circuit (*12, 13*) were designed to detect imperfections in the 0.030-in. walls of the cans. Imperfections such as cracks and pinholes might allow reactor coolant to react with the uranium and cause a slug failure. The empty cans as well as the finished slugs are not perfectly round, and earlier testers had to use a probe that rode on the can surface to reduce the noise in the signal due to changes in the probe-to-wall spacing. The derivative circuit shown in Fig. 4 almost eliminates the effect of spacing changes by emphasizing abrupt changes in the signal and de-emphasizing signal changes at frequencies that correspond to the rotational speed of the can under the probe (*13*). This tester will detect a can that has invisible cracks or buried inclusions in the wall and will differentiate between serious and superficial scratches or gouges. The sensitivity to the depth of the defects can be adjusted by changing the frequency of the a-c probe coil current. With only minor changes (*12*), the same tester can be made to detect the presence of invisible partial penetrations of the Al-Si

About Savannah River

The Savannah River Plant, built and operated by Du Pont for the AEC, isolates heavy water, fabricates reactor fuel, operates heavy-water reactors and separates and purifies reactor products. Of the original $1.3-billion cost of this plant, about $100-million was spent on instruments of all types. These instruments are maintained, improved and added to in order to keep pace with the Plant's active program of process improvement and diversification.

The Savannah River Laboratory, located on the plant site, does the longer-range research and development required to support the plant's activities. The Laboratory's Applied Physics Division, consisting of twenty-odd physicists and engineers plus an equal number of technicians and mechanics, develops and applies new instruments and principles of instrumentation to the plant's processes, as well as to the problems of health physics and research.

New "plasma thermocouple" for DIRECT CONVERSION

Experimental "plasma thermocouple," developed by Los Alamos Scientific Laboratory, converts heat from nuclear fission directly into electric power.

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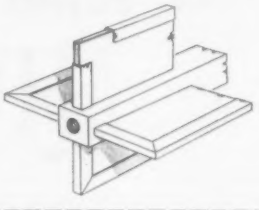
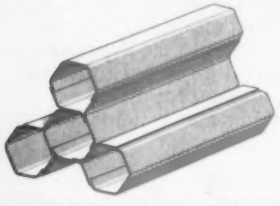
By following recommended design and fabricating practices, Boral Plate can be worked to meet the requirements of a wide range of shielding applications. It can be drilled, tapped, punched, sawed, sheared, formed, and welded. The accompanying sketches show typical designs and assembly methods.

Boral Plate is available in thicknesses of 1/16" to 3/4", and standard sheets of 30" x 48", 15" x 96", and 15" x 48". Approximate weight of 1/4" (35% B_4C) Boral Plate is 3.4 pounds.

Shut-down Control Rod for Reactors

Assembly of this unit is made by inert gas arc welding. As shown, all edges of Boral Plate should be clad. The center bar is tapped to receive the threaded rod.



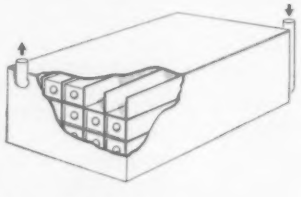


Storage Cells for Fresh Fuel

Cells are usually used in assemblies of several fuel units, encased in aluminum or stainless steel cylinders. The Boral shapes should have corner radii of 3/4"; length can be up to 12 feet. Assembly is by means of rivets or Huck bolts.

Water-cooled Boral-lined Case for Spent Fuel Elements

This Boral-lined aluminum case with egg-crate type separators for the transportation and storage of spent fuel units, is assembled from Boral Plate by arc welding; no forming operations are involved.



Typical and Potential Applications

Reactor shields, neutron curtains, shutters for thermal curtains, safety rods, storage and shipping containers for fissionable material, fabricated boxes for radiation-sensitve devices, protective shields for easily activated components.

Brooks & Perkins, the first commercial producer of Boral, invites you to send for technical data and literature. 60-T-4

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bonding layer into the protective aluminum cladding of a completed fuel slug.

Hand-held probes that produce eddy currents can be used to measure plating or cladding thickness over either a magnetic or a nonmagnetic substance (*16*). Figure 5 shows two circuits used.

Mechanical Gages

The gaging of the interior dimensions of tubes over 10 ft long and only 2–3 in. in diameter with conventional tools takes many hours. Linear differential transformers can be adapted to this problem (*17, 18*). A typical i.d. gage pushed down a tube provides continuous gaging accurate to ±0.001 in.

Radiation Gages

Penetrating radiation can be used in the nuclear nondestructive test field in rather unusual ways. The cladding thickness of a uranium slug can be measured by the attenuation of the radiation from the uranium itself (*19*). An americium-241 gamma-ray source can be used to measure the density of aluminum alloys by straightforward absorptiometer techniques (*20*).

The control-rod "worth" of neutron-absorbing elements is determined by their "blackness" to neutrons. A "blackness tester" (*21*) is used to verify the worth of assembled control rods. A paraffin-moderated neutron source produces a beam of slow neutrons. The attenuation of the neutron beam while passing through the suspect control rod is measured with BF_3 counters and a counting-rate meter.

The reactivity of fuel or control-rod elements can be quickly and cheaply measured in a small subcritical reactor. Such a device, called the Nuclear Test Gage or NTG (*22*), has proved useful. The differential electrometer (*23*) used with the NTG to measure small changes in ion-chamber current is exceptionally stable. The readout device is a recorder with a 10-in.-wide strip chart. The drift band was less than 0.1% in 4 hr with a suppressed zero span of 1.0×10^{-13} to 1.0×10^{-13} ampere.

* * *

The information contained in this article was developed during the course of work under contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

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(*Continued on page 96*)

Technician is setting controls for the assaying run. Picker equipment (left to right) Magnascaler, (below it) High Voltage Supply, Automatic Sample Changer with Detector, Readout Printer.

takes time and labor out of a tedious job

If you are doing blood-brain barrier studies in order to investigate how different drugs get into the brain, you will probably be using many rats, guinea pigs, or monkeys. Each of these test animals will ultimately have to be sacrificed for brain dissection. Then, if you have used Carbon^{14} or Phosphorus^{32} to tag the drugs, each brain section (cortex, cerebellum, etc.) will have to be counted. In such cases the use of an automatic sample changer not only saves many hours of a technician's time but also improves the accuracy of the measurement by furnishing printed data.

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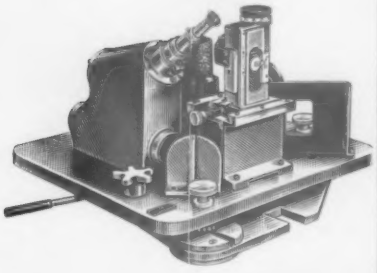

Tests tensile properties of radioactive materials at reactor temperatures

This Optical Strain-Measuring Instrument was designed for nuclear reactor development work. It permits precise determination of the tensile properties of irradiated fuel and structural materials at reactor temperatures.

Gaertner Scientific Corporation, designers of the instrument, had this problem to overcome: extremely accurate measurement of elongation must be made even when the specimen itself is inaccessible due to radiation and temperatures up to 800° C.

To solve the problem, Gaertner developed a special mechanical-optical system to measure elongation of a specimen with direct reading to 50 micro-inches.

The optical system has a working distance of more than 24 inches, permitting the insertion of shielding between the optical unit and the furnace . . . the light travels through six inches of lead-glass shielding and the quartz window of the furnace. This allows the operator to observe the specimen closely and yet be completely safe from radiation hazard.

Wide range measurement is possible . . . the micrometer moves through 0.5 inches for a one-inch specimen. This makes it possible to measure elongation-to-failure of many irradiated fuels and structural materials.

The Optical Strain-Measuring Instrument is one of *many* precision optical instruments designed and manufactured by Gaertner to measure dimensional changes of specimens under various environmental conditions.

Write for Bulletin 161

Gaertner SCIENTIFIC CORPORATION 1257 Wrightwood Ave. Chicago 14, Illinois

This article starts on page 90

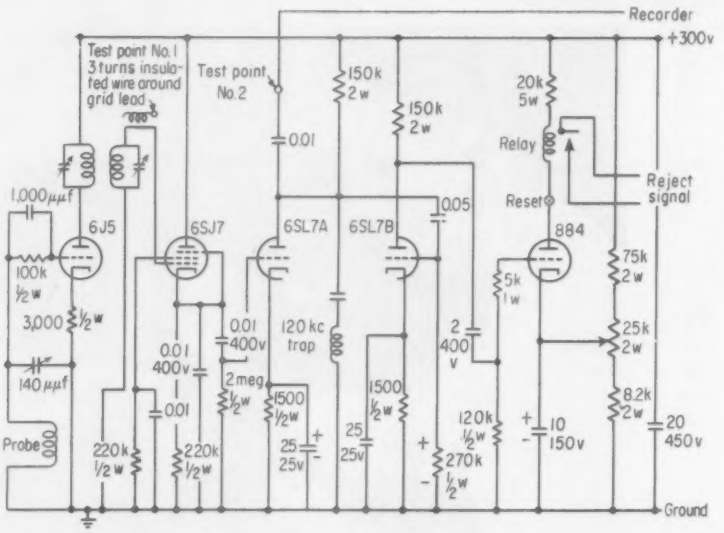

FIG. 4. ED)Y-CURRENT CAN TESTER. Derivative circuit minimizes effect of probe-to-can-wall spacing, permitting use of probe that does not contact soft aluminum can

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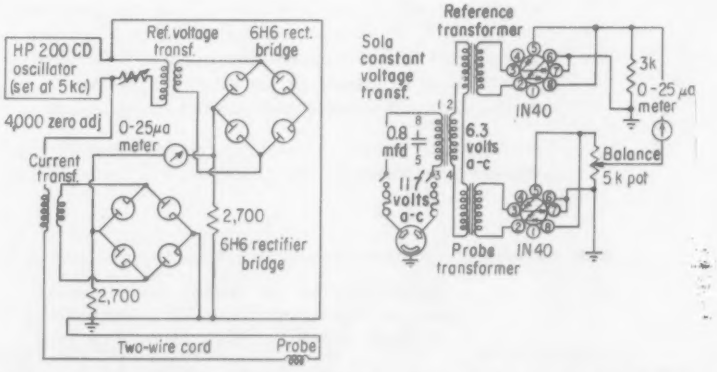

FIG. 5. TYPICAL EDDY-CURRENT CIRCUITS. Circuit (left) can be adjusted to measure thickness of aluminum over nickel layer of variable thickness (14). Circuit (right) was used to measure thickness of nickel plating on nonmagnetic base (16)

SENIOR POSITIONS
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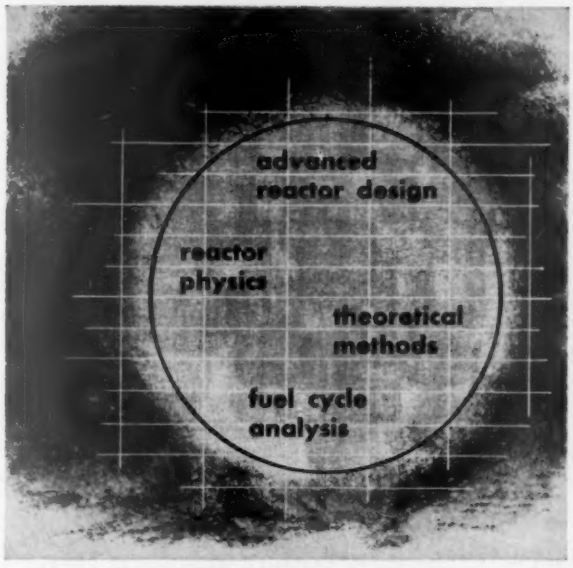

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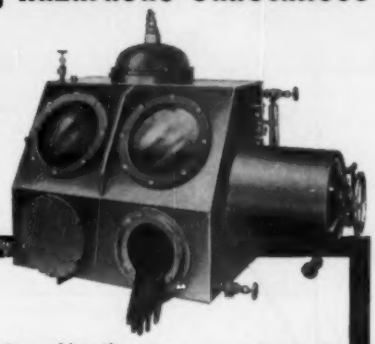

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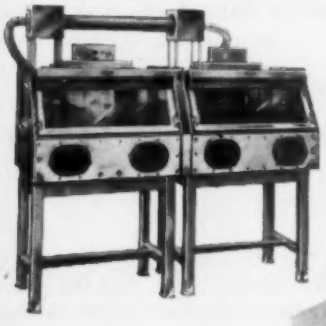

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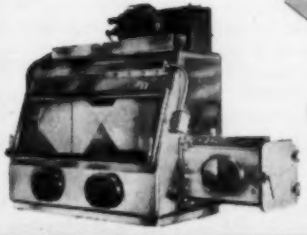

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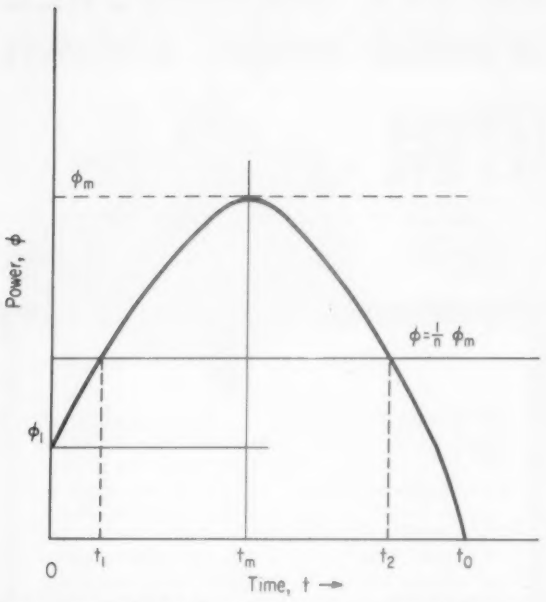

FIG. 1. Variables that describe reactor power burst include the initial power ϕ_1, the peak power ϕ_m which occurs at time $t = t_m$, and times t_1 and t_2 defined by $\phi(t) = \phi_m/n$

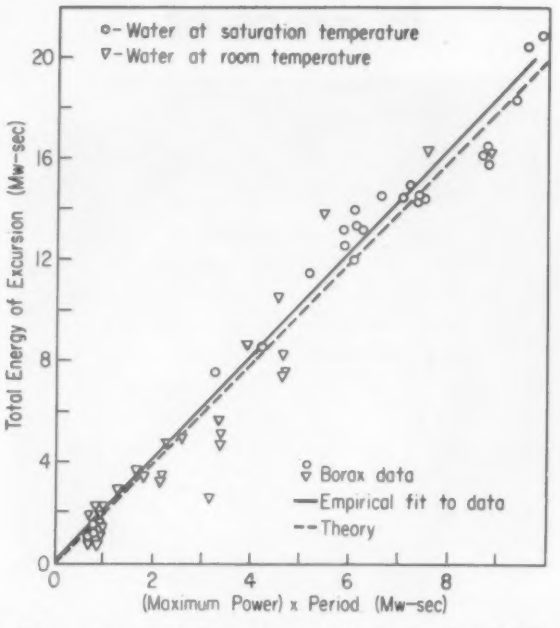

FIG. 2. Agreement of Eq. 3 (dotted line) with data from BORAX experiments. Equation predicts no dependence on water temperature which is borne out by experimental points

Simple Relations Describe Reactor Power Bursts

In a recent report,* H. C. Corben (Thompson Ramo-Wooldridge) has worked out some relations between the variables that describe a reactor power burst. Starting only with the assumptions that the power reactivity coefficient is negative and that the initial reactor period is short, Corben obtains the following amazingly simple expressions:

$$\phi_m = \tfrac{1}{2}\phi_1 e^{\alpha t_m} \quad (1)$$

$$\tau\phi_m = \tfrac{1}{3}E(\phi_m) \quad (2)$$

$$E_{tot} = 2\tau\phi_m \quad (3)$$

$$t_2 - t_1 = \tau \ln \frac{1 + \left(1 - \frac{1}{n}\right)^{1/2}}{1 - \left(1 - \frac{1}{n}\right)^{1/2}} \quad (4)$$

Here $\tau = \dfrac{1}{\alpha}$ is the initial period and ϕ_1 the initial power. Equation 1 says that the peak power ϕ_m (see Fig. 1) is related through these constants to the time t_m to reach the peak. Equations 2 and 3 give $E(\phi_m)$ (the area under the curve up to t_m) and E_{tot} (the area under the curve up to t_0) in terms of these quantities.

Equation 4 gives the width of the power burst at $\phi = 1/n\ \phi_m$; for the special case $n = 2$ this becomes $(t_2 - t_1)_{1/2} = 1.76\tau$.

Basic Argument

Corben considers a reactor that starts off at time $t = O$ with initial excess reactivity Δk_0. The power initially behaves as $\phi = \phi_1 e^{\alpha t}$, where ϕ_1 is the reactor power at $t = O$, and α is the inverse period related to the constant Δk_0 by the in-hour equation

$$\Delta k_0 = \alpha\left(l + \beta \sum_j \frac{a_j}{\alpha + \lambda_j}\right) \quad (5)$$

As the reactor power increases it will cause a change in excess reactivity through some physical feedback mechanism such as thermal expansion. Corben leaves this mechanism completely unspecified except to assume that it is negative (i.e., an increase in power tends to shut down the reactor) and writes for the Δk at some later time t

$$\Delta k = \Delta k_0 - \int_0^t G(t - t')\phi(t')\,dt' \quad (6)$$

where G is some unspecified function that relates the reduction in reactivity to the integrated reactor power. If in the integrand we set $\phi = \phi_1 e^{\alpha t}$ and redefine the variable of integration, then

$$\Delta k = \Delta k_0 - \phi_1 e^{\alpha t} \int_0^t G(x) e^{-\alpha x}\,dx \quad (7)$$

For sufficiently large α the integral is relatively independent of its upper limit t and can be replaced by a constant; hence

$$\Delta k = \Delta k_0 - \Delta k_1 e^{\alpha t} \quad (8)$$

(Continued on page 100)

* RWC 22-127 The Ramo-Wooldridge Corp. (1958)

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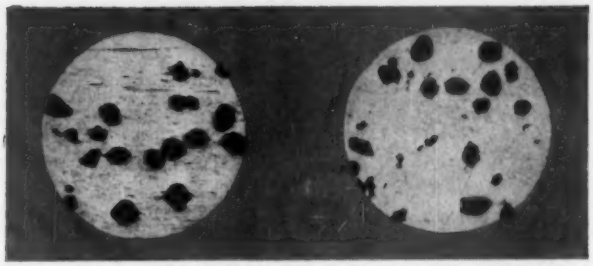
NARROWING THE "DEPARTURE FROM IDEALITY" IN DISPERSION FUEL DEVELOPMENT



† Longitudinal section of 200-μ UO_2 dispersed in Zircaloy matrix. 30X. BF. Reduced approximately 38% for reproduction.

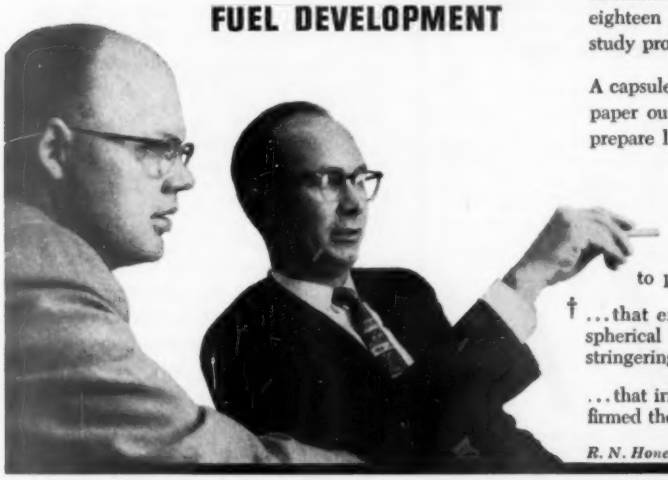
Transverse section of 200-μ UO_2 dispersed in Zircaloy matrix. 30X. BF. Reduced approximately 38% for reproduction.

Scientists have long been cognizant ot the theoretical advantages of applying the dispersion theory to reactor fuel elements. Ideally this concept could be utilized to extend substantially fuel rod life in high performance water cooled reactors.

But it remained for KAPL Metallurgists Dr. A. P. Beard and R. N. Honeyman to solve basic problems of process metallurgy involved and achieve *actual fabrication* of zirconium-alloy base dispersion elements which were a significant step closer to the theoretical ideal.

Encouraged by Dr. C. E. Weber, Manager of Basic Materials Development, and a leading figure in Dispersion Element research — and aided by consultation with specialists in several KAPL laboratories — Beard and Honeyman successfully completed evaluation of the irradiation behavior of their first samples in September 1958, only eighteen months (and 2 volumes of experimental data) after the study program was formally initiated.

A capsule description of their findings appears below. Reprints of a paper outlining the experimental method and techniques used to prepare laboratory samples will be furnished on request.



R. N. Honeyman (l.) and A. P. Beard (r.)

Summary of Findings: Dispersion Fuel Study

...showed that mechanical attritioning could be used to prepare zirconium powder with high corrosion resistance.

† ...that extrusion of dispersions of 200 micron dia. particles of spherical UO_2 & UC could be achieved at 750° C with little or no stringering and no reaction between particles and Zircaloy matrices.

...that irradiation behavior of zirconium base dispersion fuels confirmed theoretical concepts of such systems.

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where Δk_1 is a constant $<< \Delta k_0$.

This change in Δk caused by the power feedback will in turn feed back into the expression for ϕ. Corben argues that the behavior of ϕ with this mutual feedback can be expressed as an expansion in powers of $e^{\alpha t}$. He finds that the first two terms of this expansion,

$$\phi = \phi_1 e^{\alpha t} - \phi_2 e^{2\alpha t} \qquad (9)$$

are adequate to give a quantitative description of many of the interesting features of a power burst. For instance, Eq. 1 is derived by setting the derivative of Eq. 9 equal to zero, Eq. 2 by integrating Eq. 9 to t_m. Eqs. 3 and 4 also follow from Eq. 9 through simple algebra.

Validity

Comparison with experimental numbers gives surprisingly good agreement for Eqs. 1–3. Eq. 1 checks within experimental error for the SPERT, KEWB and Godiva reactors (data exist for periods as long as 0.1 sec) and comes within a factor of two for the BEPO reactor on a 28-sec period. Eqs. 2 and 3 fit the experimental points available for SPERT, KEWB and BORAX (see Fig. 2).

Equation 4 agrees within experimental error for the faster SPERT transients ($\tau \leq 35$ ms) but underestimates the pulse duration for longer periods.

The remarkable thing about Eqs. 1–4 is that they are derived without reference to any particular shutdown mechanism or even to the details of reactor kinetics (such as the existence of delayed neutrons); the only assumptions that entered in were that α had to be large and the power coefficient negative. Corben points out that, conversely, since the quantities in Eqs. 1–4 are independent of feedback mechanism, then measurements of these quantities will not give any information about feedback mechanisms (provided the series of Eq. 9 converges rapidly).

By bringing in the kinetic equations, Corben derives another expression that gives the difference between the initial excess reactivity and the excess reactivity at t_m (i.e., the reactivity compensated by the reactor up to time t_m)

$$\Delta k_c = \Delta k_0 - \Delta k_m = \alpha\left[1 + \beta \sum_j \left(\frac{a_j \lambda_j}{(\alpha + \lambda_j)(2\alpha + \lambda_j)}\right)\right] \qquad (10)$$

Inspection of the value of Δk_c for limiting values of α shows that

$$\underset{(\alpha\to 0)}{\Delta k_o} < \Delta k_c < \underset{(\alpha\to\infty)}{\Delta k_o - \beta}$$

We see that the compensated reactivity depends only on the constant α, the prompt neutron lifetime, and the customary delayed-neutron parameters.

Hazard Estimates

For the reactor engineer doing a typical hazards calculation who wants to know the total energy release and so forth that results from a given jolt of excess reactivity, Corben's relations are not sufficient by themselves. For instance, with the initial period and power specified, each of the Eqs. 1–3 still contains two unknowns. This indeterminacy is not surprising since, as we mentioned, the equations have not made use of any information about the physical characteristics of the reactor which would certainly have an influence on things like total energy release.

Possibly the simplest approach is to try and crank the extra information needed into Eq. 6. From the definition of Δk_c we have

$$\Delta k_c = \int_o^{t_m} G(t - t')\phi(t')\, dt'$$

By replacing the unspecified function G with some reasonable approximation based on the design of the reactor in question, the engineer might provide a relation between Δk_c and the energy release. For example the crudest approximation would be to set G equal to a constant; then

$$\Delta k_c = G \int_o^{t_m} \phi(t')\, dt' = G\, E(\phi_m) \quad (11)$$

Since Δk_c can be obtained for a given α from Eq. 10, then $E(\phi_m)$ is fixed by Eq. 11 and the quantities ϕ_m, t_m and E_{tot} are available through Eqs. 1–3. However, usually it would not be realistic to set G equal to a constant.

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Statistical Analysis of Power-Reactor Noise

By J. A. THIE
Argonne National Laboratory, Lemont, Illinois

The rate of fission in a reactor operating at a certain power level does not remain perfectly constant with time but fluctuates in a random way about an average value. This reactor "noise," because it stems from statistical fluctuations in reactivity inherent in the system (such as turbulent flow of the coolant), is present as an unavoidable condition in all reactors. However, there is a way to put reactor noise to some use—a frequency-spectrum analysis of the noise can provide, essentially "free-of-charge," some interesting information about reactor kinetic performance.

Fourier transform methods already used to analyze the radar signals, light from twinkling stars, etc. permit one to determine the distribution of frequency components present in reactor power fluctuations. Once we have this frequency distribution, we can extract from it various kinds of information:

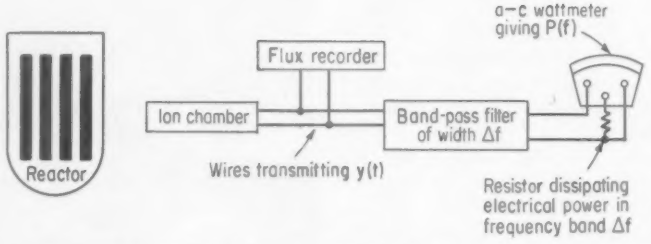

FIG. 1 CONCEPTUAL EXPERIMENTAL ARRANGEMENT to analyze frequency distribution of statistical fluctuations in reactor power directly from ion-chamber signal. For work reported in article, author obtained frequency distribution through analysis of power trace with numerical methods

- A recording of reactor flux fluctuations is all the experimental information needed to detect sharp resonances in reactor transfer functions. (For precise measurement of broad resonances, a knowledge of the approximate shape of the noise spectrum driving the reactor is helpful.)
- In zero-power reactors noise analysis will give the neutron lifetime (*1*).
- For other reactors the coefficients in the differential equations governing dynamic behavior can be obtained (*2, 3*).
- A power spectrum derived from noise analysis together with a measured or calculated transfer function will yield information about the basic causes of reactor noise.
- Continual monitoring of reactor noise could provide an additional safety check for the reactor operator. For instance, an analog computer might continuously analyze the fluctuations (see Fig. 1) and display the instantaneous power spectrum to the operator, who could check it for the appearance of resonances.

The relation of this method to rod-oscillator tests is discussed in the box below.

Noise Analysis and Rod-Oscillator Tests —How Do They Compare?

In general the information we get from reactor-noise analysis is obtained without interfering with the operation of the reactor. Figure 1 shows an idealized arrangement for this purpose. The method is much less costly than other methods.

An example of an alternative method is the rod-oscillator test, which is well established as a tool for exploring reactor dynamics. Stringent tests of theories about reactor dynamics are possible only by this method; hence it will remain as the ultimate technique where high precision is sought at the expense of time, money, manpower and equipment. However, as reactor development progresses from the scientific-experimental to the industrial-engineering stage, the need for such experiments decreases. In their place we will have a need for simple rapid tests that give direct final answers. Here the analysis of spectra from reactor noise will come to the fore. Information can be obtained in this way without disturbing the reactor's structure or operating schedule and without skilled experimentalists.

The rod-oscillator tests on EBWR (4) yielded transfer functions over a wide frequency range for a dozen different conditions. Several staff man-months and technician man-months were required; the mechanical and electronic equipment cost about $10,000, and 3–8 hr of reactor time was used up for each transfer function.

With the statistical method the costs are much less. About one man-month is enough for a mathematician to collect up to a dozen power spectra. Fast chart recorders of flux cost up to $2,000. In addition, each spectrum shown here required 2 min of reactor time, 3 hr to obtain punched cards, and about 10 min of IBM-704 time.

The precision of the results for EBWR was ±0.5 and ±2.6 db in reactor transfer functions by the rod-oscillator and statistical methods, respectively. Where less accuracy is needed, a "poor man's" rod oscillator test is the "ringing" experiment: one observes the reactor response to a single rapid motion of a control rod (5). Similarly a "poor man's" statistical technique can give semi-quantitative results by (a) using an order of magnitude fewer points than we used here and (b) using smaller computing machines, possibly even desk calculators.

Power Fluctuations

Encouraged by preliminary studies (*6, 7*), we undertook more intensive studies of the noise-analysis technique; we chose the EBWR as a subject because of its "noisy" nature and its well-studied behavior (*4*).

The top two traces of Fig. 2 show

the actual EBWR flux fluctuations. Casual inspection indicates that frequencies near 1 or 2 cps seem to be dominant. This is quite characteristic of boiling reactors (*8*). To facilitate analysis (*9*) by the IBM 704 we digitized these traces at intervals Δt with a Benson-Lehner chart reader coupled to an IBM card puncher.

A histogram of the fluctuation amplitudes in Fig. 3 shows a Gaussian behavior. To get a more quantitative analysis we compared the distribution of fluxes y_i's with a Gaussian of the same mean $\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$ and standard deviation $S = (\overline{y^2} - \bar{y}^2)^{1/2}$:

	45.6-Mw EBWR data	*Gaussian distribution*
Fraction of y_i's where $\lvert y_i - \bar{y}\rvert > S$	0.325	0.3173
Fraction of y_i's where $\lvert y_i - \bar{y}\rvert > 2S$	0.039	0.0455
$\frac{y_i\text{'s} > \bar{y}}{y_i\text{'s} < \bar{y}}$	0.9863	1

This amplitude distribution provides the first quantitative measurement of the so-called "roughness" or "instability" of reactor flux. We see that for EBWR at 45.6 Mw(th) the standard deviation of reactor power is 0.83 Mw and the probability per second that the reactor power will exceed $45.6 + 2 \times 0.83 = 47.26$ Mw is $\frac{1}{2} \times 0.039/0.05 = 0.34$ sec^{-1}.

Autocorrelation

Fourier analysis of reactor power fluctuations $y(t)$ yields the spectral power distribution $P(f)$, as follows:

$$P(f) = \lim_{T\to\infty} \frac{1}{T} \left| \int_{-T/2}^{T/2} y(t) \exp(-i2\pi ft)\, dt \right|^2 \quad (1)$$

Although in principle Eq. 1 can be used directly for spectral analysis, in practice the intermediate use of the autocorrelation function is preferred (*10*). This function $\varphi(\tau)$ is defined as

$$\varphi(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} y(t)y(t+\tau)\, dt \quad (2)$$

If

$$y(t) = \int_{-\infty}^{\infty} Y(f) \exp(i2\pi ft)\, df \quad (3)$$

then substitution into Eq. 2 gives

$$\varphi(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} Y(f)Y(-f) \exp(i2\pi ft)\, df \quad (4)$$

and substitution into Eq. 1 gives

$$P(f) = \lim_{T\to\infty} \frac{1}{T} |Y(f)|^2 \quad (5)$$

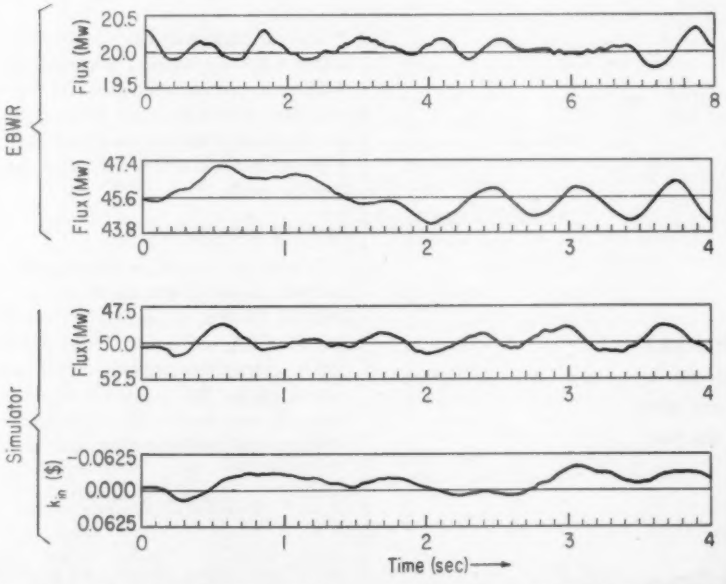

FIG. 2. STATISTICAL FLUCTUATIONS in reactor power were observed directly in EBWR (two top traces) and simulated by analog computer (bottom traces). Bottommost of latter shows reactivity variation fed into computer while trace above it shows resulting flux variation

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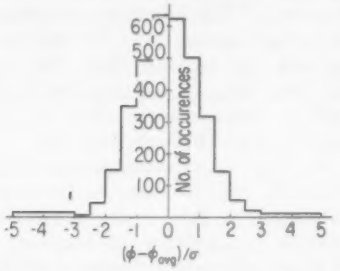

FIG. 3. HISTOGRAM of EBWR flux in 3,331 consecutive 0.05-sec intervals for 45.6-Mw operation. Quantity plotted horizontally $(\varphi - \varphi_{avg})/\sigma$ is deviation of instantaneous flux from average flux divided by standard deviation

Hence,

$$\varphi(\tau) = \int_{-\infty}^{\infty} P(f) \exp(i2\pi ft)\, df \qquad (6)$$

and

$$P(f) = \int_{-\infty}^{\infty} \varphi(\tau) \exp(-i2\pi ft)\, dt = 2\int_{0}^{\infty} \varphi(\tau) \cos 2\pi ft\, dt \qquad (7)$$

This result is Wiener's theorem: the power spectrum of a function is the Fourier transform of its autocorrelation function.

Figure 4 shows $\varphi(\tau)$ for the traces of Fig. 2. The y's used in Eq. 2 for this were more conveniently taken as the reactor flux minus its average value. Features of the autocorrelation function that would be anticipated from Fig. 2 are:

- The correlation among reactor fluxes within a 0.1-sec interval is quite high.
- The correlation among reactor fluxes separated by a time equal to the period of a resonant frequency is also high.
- There is little correlation over long time intervals.

Analog Simulation

To provide a check on the methods of analysis used, we simulated the operation of EBWR at 50 Mw(th) on the PACE analog computer. Information obtained from an analysis of the flux calculated by the computer could be precisely compared with expectations. We used the following equations (*8*):

$$\frac{l}{N_0}\frac{dn}{dt} = (1-\beta)k - \beta\frac{n}{N_0} + \sum_i \lambda_i l \frac{c_i}{N_0} \qquad (8)$$

$$\frac{l}{N_0}\frac{dc_i}{dt} = \beta_i k + \beta_i \frac{n}{N_0} - \lambda_i l \frac{c_i}{N_0} \qquad (9)$$

$$\frac{1}{H_0}\frac{dh}{dt} = \frac{\alpha}{N_0}n - \alpha\frac{h}{H_0} \tag{10}$$

$$\frac{1}{V_0}\frac{dv}{dt} = \gamma\frac{h}{H_0} - \gamma\frac{v}{V_0} \tag{11}$$

$$\frac{1}{H_0}\frac{dh'}{dt} = \frac{\alpha'}{N_0}n - \alpha'\frac{h'}{H_0} \tag{12}$$

$$\frac{1}{X_0}\frac{dx}{dt} = -\delta\frac{h'}{H_0} - \delta\frac{x}{X_0} \tag{13}$$

$$\frac{1}{V_0'}\frac{dv'}{dt} = -\gamma'\frac{x}{X_0} - \gamma'\frac{v'}{V_0'} \tag{14}$$

$$k = \frac{dk}{dv}(v + v') + k_{in} \tag{15}$$

These are the linearized set previously introduced (*5*) except for an additional feedback which comes from deviations x of the subcooled length from its equilibrium value X_0 (*7*, *8*). Here $h + H_0$ and $h' + H_0$ are heat-transfer rates in the boiling and subcooled sections respectively; $v + V_0$ and $v' + V_0'$ are void volumes due to energy generated in the boiling and subcooled sections respectively. Pressure changes can be ignored except at very low frequencies.

For EBWR at 50 Mw and 600 psig

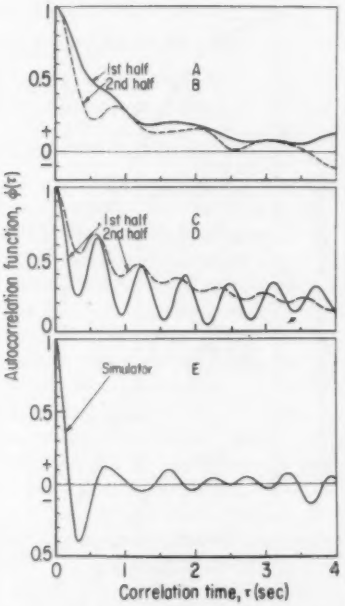

FIG. 4. AUTOCORRELATION FUNCTIONS derived from EBWR power traces (top curves) and trace simulated by analog computer (bottom)

	Power (Mw)	Press. (psig)	N	M	t (sec)
A	20	550	1,400	200	0.05
B	20	600	696	100	0.1
C	45.6	600	1,668	300	0.05
D	45.6	600	1,663	300	0.05
E	50	600	696	100	0.1

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the four time constants are: fuel-plate time constants in the boiling and subcooled zones respectively, $1/\alpha = 0.328$ sec and $1/\alpha' = 0.389$ sec; the average time for subcooled water to reach the boiling boundary, $1/\delta = 0.1711$ sec; the average times for voids to leave the core when formed in the boiling zone and at the boiling boundary respectively, $1/\gamma = 0.1183$ sec, and $1/\gamma' = 0.1775$ sec. The reactivities associated with these two sources of voids are respectively, $V_0\, dk/dv = -0.02588$ and $V_0'dk/dv = -0.03307$.

If we theorize that the reactivity driving force k_{in} of an undisturbed boiling reactor is due to fluctuations in bubble content caused by random heat-content fluctuations q in the entering water, then:

$$\frac{1}{X_0}\frac{dx'}{dt} = -\frac{\delta}{2}\frac{q}{Q_0} - \frac{\delta}{2}\frac{x'}{X_0} \qquad (16)$$

$$\frac{dk_{in}}{dt} = -\gamma' V_0' \frac{dk}{dv}\frac{x'}{X_0} - \gamma' k_{in} \qquad (17)$$

Here x' represents fluctuations in the

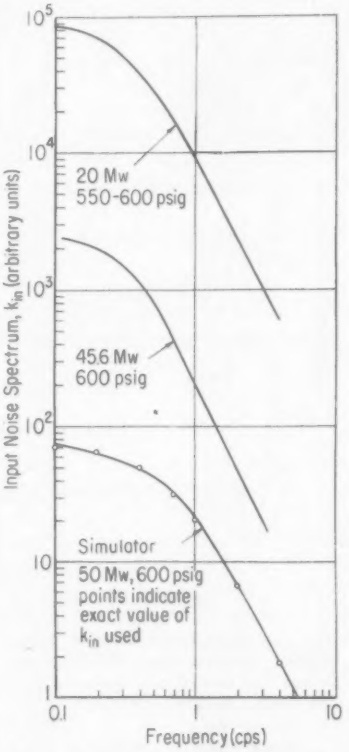

FIG. 5. FREQUENCY DISTRIBUTION, $P(f)$, of reactor noise for two levels of EBWR operation and simulated operation at 50 Mw. Distributions are calculated from $\varphi(\tau)$ (see Fig. 4) through Eq. 7

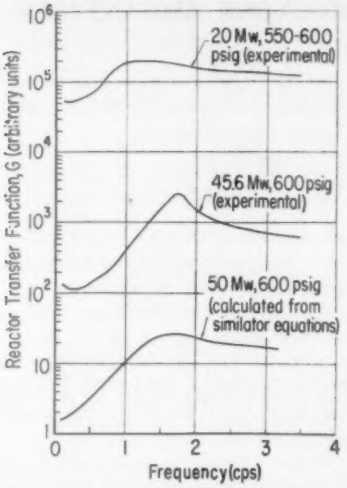
20 Mw, 550-600 psig (experimental)
45.6 Mw, 600 psig (experimental)
50 Mw, 600 psig (calculated from similator equations)
Reactor Transfer Function, G (arbitrary units)
Frequency (cps)

FIG. 6. REACTOR TRANSFER FUNCTIONS measured by rod-oscillator tests in EBWR (upper curves) and calculated from analog results (lower curve)

boiling boundary due to the random fluctuations q.

In the analog runs we generated a "white" noise (i.e., a power spectrum independent of frequency) to represent q. Fourier analysis of Eqs. 16 and 17 shows (see Fig. 7) that the k_{1n} that results from this q is also "white" except at high frequencies.

Power-Spectrum Analysis

Figure 5, which is a Fourier analysis of Fig. 4 according to Eq. 7, shows the resonance behavior noted earlier in EBWR (*5*). The stronger resonance at the higher flux level agrees with the earlier findings. By analyzing the 45.6-Mw flux record in two parts we obtained the statistical uncertainty of the result. Figure 4 shows that the autocorrelation function was more strongly damped in the second half of the record. Thus, the resonance should be slightly broader and lower, as indeed is the case in Fig. 5.

This observed statistical uncertainty in the strength of the resonance can be quantitatively predicted. For a trace $N\,\Delta t$ in length and for which the largest lag in computing the autocorrelation function is $M\,\Delta t$, a bandwidth of $7.07[(N/M) - 5/6]^{-1/2}$ db will contain 60% of the spectral estimates (*11*). In Fig. 5 this is 2.6 db for the 45.6-Mw case, and almost fortuitously 61% of the pairs of points are in this band.

A second important consideration is the resolution Δf obtained; this is given by $\Delta f = 1/(M\,\Delta t)$ (*11*). Hence a compromise must be made. The above formula for statistical uncertainty indicates that high resolu-

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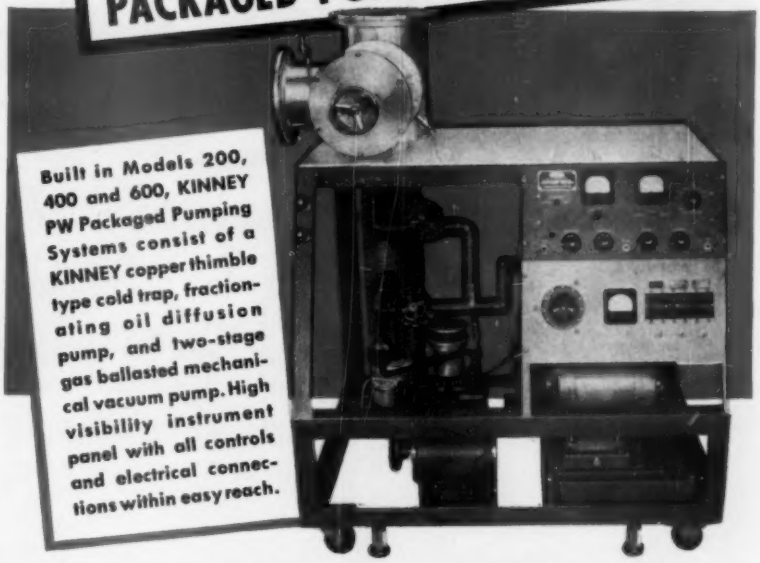

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This article starts on page 102

tions mean high statistical uncertainty. By using a smoothing technique called "hamming,"

$$\bar{P}(f) = 0.23P(f - 0.5\,\Delta f) + 0.54P(f) + 0.23P(f + 0.5\,\Delta f) \quad (18)$$

one obtains in Fig. 5 powers which most nearly correspond to a flat-topped spectral "window" of width, Δf.

A final consideration in spectral analysis is the choice of Δt. Power amplitudes can be obtained only for frequencies below $1/(2\,\Delta t)$. The low frequency limit is set by the resolution, $1/(M\,\Delta t)$.

Figure 6 shows the measured (*4*) and calculated (*8*) transfer function, G. Since

$$\frac{n(f)}{N_0} = G(f)k_{in}(f) \quad (19)$$

by definition, then

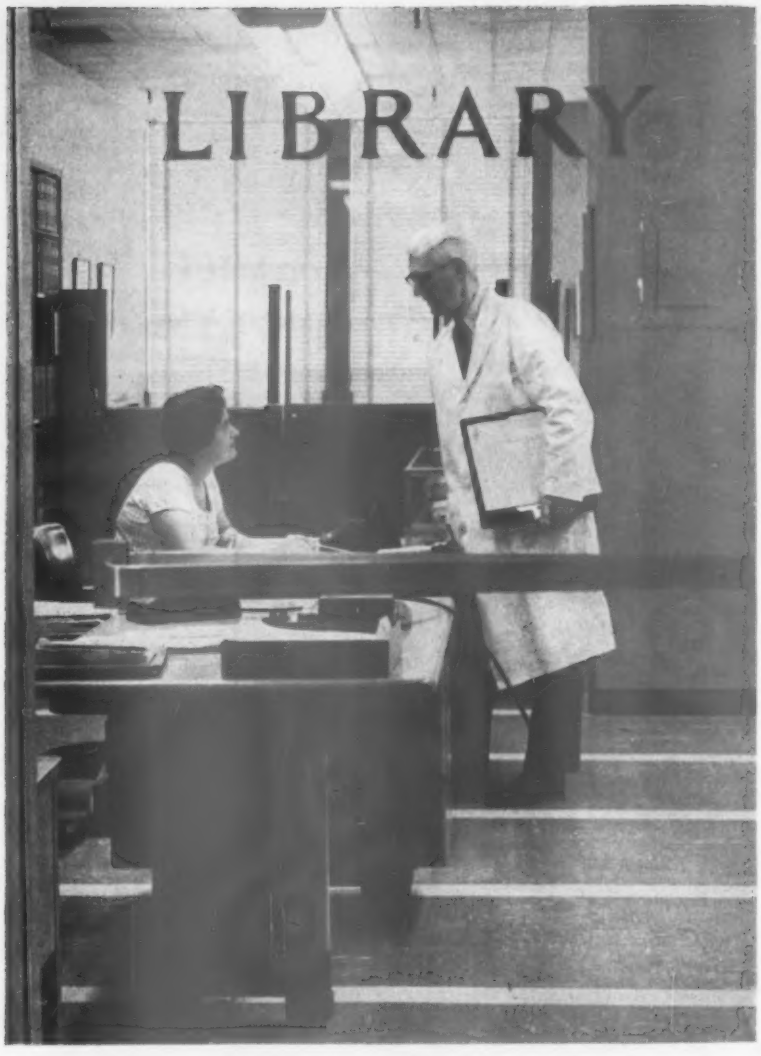
$$k_{in}(f) \sim \frac{[P(f)]^{1/2}}{G(f)} \quad (20)$$

Since Eq. 1 shows P to be the square of the Fourier amplitude of n, in Fig. 7 we divide the square root of P by G. For the simulated case the agreement between the noise spectrum so obtained and the k_{in} actually used is a check on the validity of this analysis.

The two upper curves in Fig. 7 represent experimental determinations of the reactivity driving force in EBWR. For both cases studied, the frequency spectrum of k_{in} is flat at low frequencies and attenuates at a rate of 12 db per octave above 0.3 cps. Hitherto there has been no knowledge of this function, and only theoretical speculation about its existence. However, now a quantitative knowledge of k_{in} allows comparison with theories such as Eqs. 16 and 17. The points in Fig. 7 corresponding to the latter have approximately the same frequency dependence as the experimental $k_{in}(f)$ at 45.6 Mw. This tends to lend some credence to Eqs. 10 and 11.

Reactor Stability

The power spectrum obtained by autocorrelation methods is useful in itself. If a sharp resonance appears at a particular frequency, then the reactor transfer function should have a similar resonance. The higher and sharper such resonances are, the greater the tendency of the system toward unstable oscillations at the resonance frequency. Therefore, quantitative determinations of resonances are an



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important part of evaluating a system's stability.

If, as for EBWR, transfer function measurements by the rod oscillator technique are available, then they can be used with the power spectrum to determine $k_{in}(f)$. Knowledge of k_{in} will assist in understanding the fundamental processes in boiling reactors. For most reactors, however, rod-oscil-

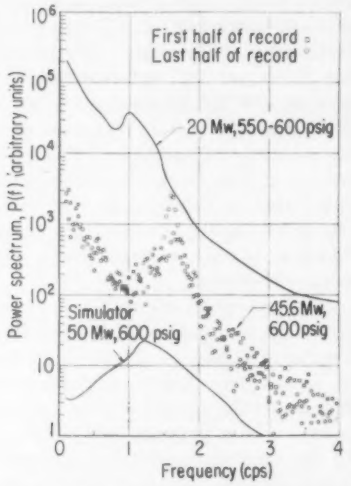

FIG. 7. INPUT-NOISE SPECTRUM derived from functions plotted in Figs. 5 and 6 gives distribution of frequency components present in reactivity fluctuations that drive reactor-power fluctuations

lator measurements are not available. The use of the power spectrum in conjunction with theoretical estimates of $k_{in}(f)$ in Eq. 20 will then give information about the reactor transfer function, $G(f)$.

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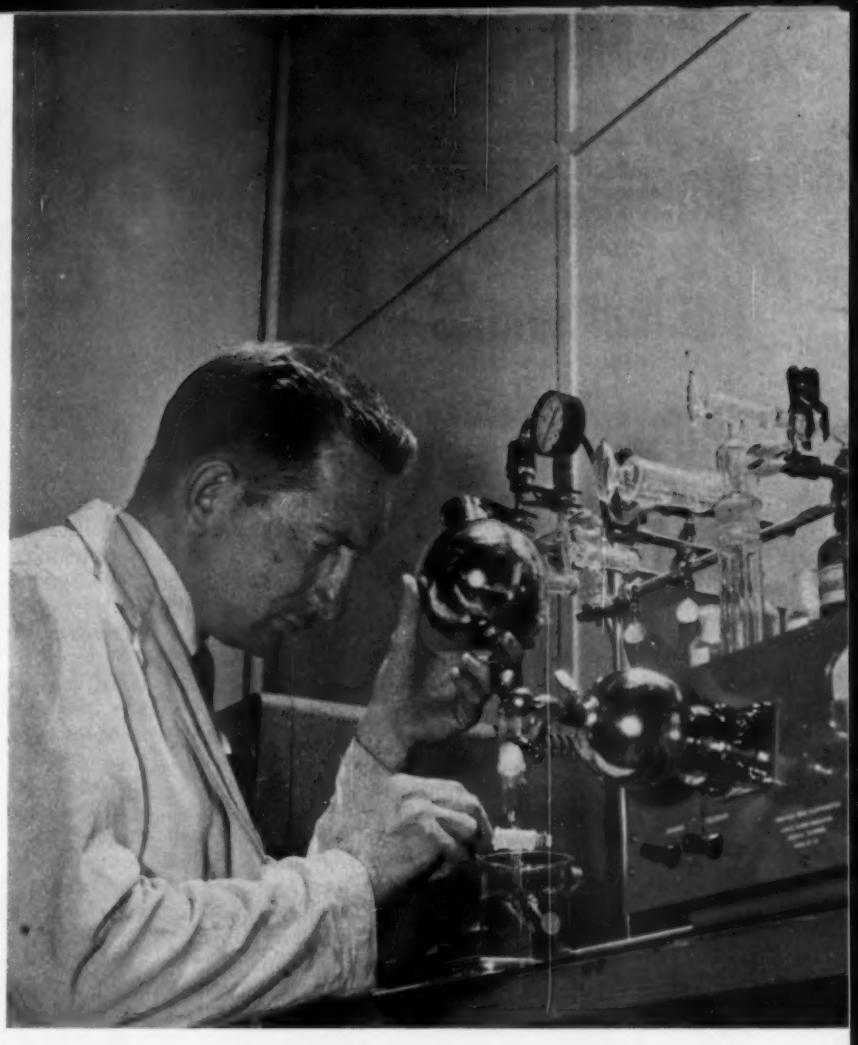

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Food Irradiators Look to Low-Dose Treatments

To one observer at least it appears that food irradiators have put off the glamor of silk dressing gowns of morning and turned to the work shirts and rolled-up sleeves of noonday. An overall look at what is going on was available at the International Conference on the Preservation of Foods by Ionizing Radiations held at the Massachusetts Institute of Technology in midsummer. Cosponsors were the Department of Food Technology of MIT, the U. S. AEC, and the International Atomic Energy Agency. Delegates from two dozen countries were there to compare notes, ask questions and get answers.

The emphasis has changed. The prize exhibit is no longer a steak that will retain color and texture without refrigeration. Instead the experts are looking to low-dose treatments as the ones most likely to have early commercial value. There may be immediate value in killing salmonellas and trichinae, deinfesting grain, extending storage life of potatoes and onions, and increasing time available for shipping foods to underfed regions. In the United States the most promising possibility appears to be low-dose irradiation of fish to extend shelf life.

Low-Dose Rates

There may also be unusual potential in low dose rates. Many delegates spoke of food problems in their countries that might be solved by radiation. Most of the problems have to do with shipping and storing food. It appears likely that a source used during storage or shipping to accomplish a given purpose might be miniscule as compared to the source that would do the job in one irradiation of limited duration. Could one, for example, store grain in an elevator with permanently installed cobalt rods. Such a low-level constant irradiation would be assured of affecting insects and microorganisms at their most sensitive stage. Perhaps it would not be difficult to place radiation sources among the packages filling the hold of a ship.

To many, potato irradiation appears to be technically feasible but economically useless. The British have given it up as uneconomical. The problem is bruising and rubbing. Meanwhile the Poles are still investigating the process, and the Russians are using it (NU, Sept. '58, p. 91). Russians with the atomic-energy portion of the recent exhibit at New York's Colliseum indicated that a 200,000-curie Co^{60} food irradiator under construction near Moscow would be used partly for potato irradiation.

Many variables can be manipulated to change the problem of bruising and healing of potatoes—notably the time of irradiation. Ability to heal is a function of the age and exposure of the potato. Thus the right dose delivered at the right time and the right rate might inhibit sprouting without increasing susceptibility to bruising.

Extended Storage

Potato and onion storage would be a boon in Central America, where the highest rate of population growth in the world and an absence of refrigeration produce a constant food problem. Potatoes are subject to variable yield and large losses. Successful storage would level the price.

Last year a pound of Central American onions cost the skilled worker an hour's wage; better storage would help. Other problems in Central America include molds in coffee and cocoa and the short shelf life of bananas. Governments might subsidize food-irradiation programs to solve commercial problems and improve local diets.

Food Poisoning

Salmonellas present different problems in different regions. In the U. S. these bacteria have only recently been recognized as pathogenic, and even now few consider them a serious problem. This is in disagreement with the opinion of many foreigners who blame salmonellas for various kinds of fairly severe food poisonings. The severity of the poisoning may not be the measure of the problem for food exporters and importers. If laws prohibit importation of foodstuffs containing sal-

monellas or distributing such materials to consumers after they are imported, exporters and importers are in trouble, and people may go hungry. For example, South Africa faces a problem in exporting liquid eggs. Salmonellas may develop during a sea voyage so that a shipment apparently free of them at departure may be infected when they arrive. Irradiation before, during or after the voyage might enable a commerce that would be otherwise impractical.

Costs Go Down

Radiation economics are improving. Paul Aebersold of the AEC Office of Isotopes Development suggests that irradiation cobalt may become cheaper if one can find some free neutrons with which to make it. For example, there may be some volume available in reactor control rods and blankets. Henry Seligman (presently with the International Atomic Energy Agency in Vienna and formerly of Harwell) indicates that the British have been looking for ways to use cobalt as a flux flattener in some of their reactors.

Meanwhile accelerator radiation is becoming ever cheaper. Walton Van Winkle, Jr., indicates that radiation sterilization of sutures at Ethicon is now about as costly as heat sterilization. Newly developed microwave amplifier tubes called "amplitrons" are expected to reduce costs by 20–45%. Accelerator manufacturers are announcing new designs with the assertion that they will be much cheaper than their ancestors.

However, where foods are concerned, many feel that the cost is not important. As exemplified by frozen food, the customer will buy a better product even when it is significantly more expensive.

Heat and radiation may be usable together for preservation that is better than either accomplishes alone. Current work is finding that many heat-resistant bacteria are radiation-sensitive and radiation-resistant ones are heat-sensitive. Thus the total damage—in terms of flavor and texture changes—might be reduced to a minimum with an optimal combination treatment.

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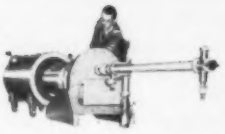

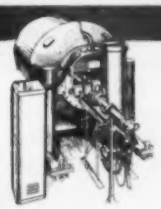

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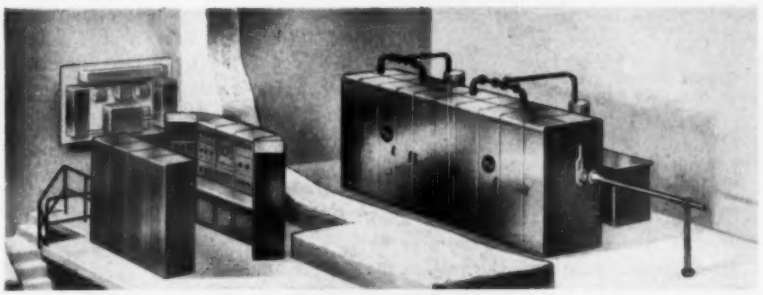

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BOOKS

A Primer of Programming for Digital Computers

By MARSHAL H. WRUBEL (McGraw-Hill Book Co., New York, 1959, 230 pages, $7.50)

This book is designed for the scientist or engineer who wants to use a digital computer as a tool in his work but who has never programmed one before. The author begins with the elementary operations and works the reader up to advanced programming schemes such as FORTRAN (FORmula TRANslation) and SOAP (Symbolic Optimal Assembly Program). Although all his discussion and examples refer specifically to the IBM 650, the principles developed are generally valid for all digital computers; he carefully alerts the reader at the places where this is not true. In summary, the book offers clearly written, down-to-earth advice ("Very few programs work correctly the first time they are tried . . .") to those who would like to try their hands at programming a "big machine."

—H. L. D.

Radioactive Isotopes in Clinical Practice

By Edith Quimby, Sergei Feitelberg, Solomon Silver (Lea and Febiger, Philadelphia, 1958; reprinted January, 1959; 451 pages.)

Reviewed by JAMES MCRAE, MRACP, Donner Laboratory, University of California, Berkeley, California.

This book is the outgrowth of a course in clinical uses of radioactive isotopes given regularly by the authors and is an excellent text for physicians who wish to understand some of the fundamental principles of radioactivity and to use isotopes intelligently. It is not comprehensive in every aspect, but it does cover the clinical use of isotopes adequately.

The book is divided into three sections:

PART I, Basic Physics, by Edith Quimby, provides a readily understood outline of subjects such as radioactivity, nuclear reactions, interaction of radiation and matter, dosage calculations for radioactive isotopes and radiation hazards and their avoidance. The chapter on the biological effects of ionizing radiation is a little disappointing. It may give a true assessment of the magnitude of the harmful effects of radiation but it is insufficient to provide orientation in a field where emotion has entered many of the discussions available elsewhere.

PART II, by Sergei Feitelberg, deals with instrumentation and laboratory methods. Again an excellent outline of the principles is presented. The essential points are made clearly and a thorough knowledge of this section allows counting procedures to be fully understood. The chapters include discussions of radiation detectors, quantitative measurements *in vitro* and *in vivo*, and determination of isotope distribution within the body. Autoradiography, use of radiation detectors in health protection and laboratory design are mentioned briefly.

PART III, Clinical Applications, by Solomon Silver, includes a comprehensive account of the place of radioiodine in elucidating thyroid physiology and disease, and a less detailed account of the clinical uses of many other isotopes. Again, the important principles are stressed and not lost in details. Adequate references are given to papers providing details of techniques.

The first two sections of the book would be valuable to anyone who proposed to use radioisotopes and who wished to understand something of their nature and measurement. The entire book is oriented for the clinician. It is clearly written throughout and provides the essential principles for the intelligent use of isotopes.

Progress in Nuclear Energy —Analytical Chemistry, Vol. 1

M. T. KELLEY, editor (Pergamon Press, New York, 1959, 372 pages, $15)

Reviewed by C. J. RODDEN, New Brunswick Area Office, U. S. Atomic Energy Commission, New Brunswick, N. J.

This volume of the "Progress in Nuclear Energy" series is a compilation of selected papers presented at the Second International Conference on the Peaceful Uses of Atomic Energy held in Geneva in 1958 and deals with the analysis of materials of interest in the nuclear field.

The fields of analysis that are covered indicate the broad scope that confronts the present-day analyst. The book is divided into "Reactor Applications," "Activation Analysis," "Spectrographic Techniques," "Industrial Applications" and "Health Physics." As would be expected in such a compilation, there are articles of interest to analysts in general, and others that are of interest to specialists only.

Several of the papers are in the nature of excellent review articles covering the analysis of thorium, chemical methods for the determination of uranium in ores and neutron activation analysis. The application of gamma-ray spectrometry to fission-product analysis and to reactor effluents indicates the versatility of this relatively new method of analysis. Akin to this is the use of gamma-ray absorption in the monitoring of uranium in process streams. X-ray spectrographic methods are described for uranium fuel alloys as well as for plutonium and uranium in solutions.

The application of the hollow-cathode discharge to the analysis of zirconium and its compounds and the spectrographic determination of oxygen, nitrogen and hydrogen in metals are of interest. Many of the papers deal with specific subjects such as the analysis of plutonium by controlled potential coulometry, the determination of Sr^{89} and Sr^{90} in urine and sea water and heavy-water monitoring by infra-red spectroscopy.

The assembling of the important analytical chemistry papers of the 1958 Geneva Conference results in one conveniently handled volume that can be very useful to the analyst dealing with nuclear materials. All papers are in English with the exception of two that are in French. Why these two papers were left in the original language is not understandable, since translations are available.

Nuclear Rocket Propulsion

By R. W. BUSSARD and R. D. DELAUER (McGraw-Hill Book Co., New York, 1958, 370 pages, $10)

Reviewed by G. W. ELVERUM, Jr., Advanced Propulsion, Space Technology Laboratories, Inc., Los Angeles, Calif.

An examination of the propulsion-system requirements for various space missions shows that deep space exploration by large manned vehicles will likely require the use of nuclear energy. In this book, the authors present the engineering foundation on which to base the design of vehicles using high-power-density fission reactors as the primary energy source for several types of rocket engines.

While at the Los Alamos Scientific Laboratory, both of the authors worked on this country's first research program to demonstrate a nuclear rocket motor. As a result, their book includes the most up-to-date concepts and design data in both the areas of rocket-vehicle-system

analysis and reactor design and control.

After a brief introduction, a chapter on *Basic Rocket Performance* gives derivations of the parameters characterizing the performance of rocket engines and describing the rocket vehicle's motion. This is followed by *System Analysis*, which relates the performance and weight of each major component to the over-all vehicle performance. Values of all the required coefficients in the component weight and performance equations are given based on current vehicle engineering design practice. These equations provide the nonspecialist on design with all of the information required to evaluate the relative ideal capabilities of vehicles using various propulsion-system concepts.

The fourth chapter presents a review of some of the fundamentals of *Heat Transfer and Fluid Flow*. Of great interest to designers of all types of high-power-density reactors are sections relating power density to core geometry and working-fluid core pressure drops. The next chapter, *Materials*, discusses the special problems encountered in the very high-temperature, high-stress regions. While the properties of various materials are given in some detail, it is apparent that much of the uncertainty in the engineering design of high-temperature, high-power-density reactors lies in this area. The discussion emphasizes the unusual materials requirements and should serve to stimulate and guide the large amount of experimental research work required.

A chapter on *Nucleonics* follows, in which reactor statics, kinetics and gamma and neutron leakage are discussed from the engineering standpoint. A description of the physical processes involved and several methods of reactor analysis are given. Although some of the approximate methods are shown to provide information for early survey design work, it is properly pointed out that detailed evaluation of a particular reactor must be carried out on a large high-speed digital computer. Thus, while this part of the book is useful as an engineering guide, the actual computation of the neutronic analysis will probably always be done using one or another of the computer codes available through the AEC.

A general approach to the problems of *System Control* are given in the next chapter. Some of the mathematical methods of control-system analysis and the use of analog simulation to study system dynamics of nuclear rocket engines are presented.

The remainder of the text is devoted

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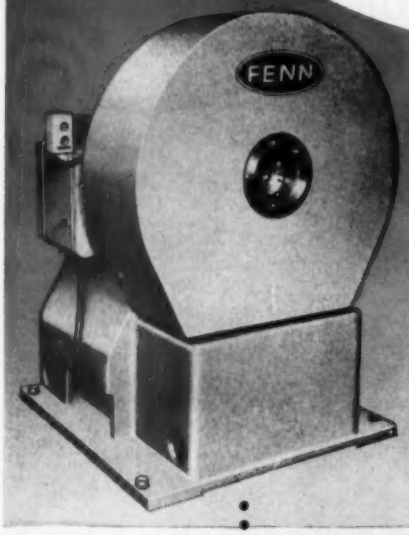

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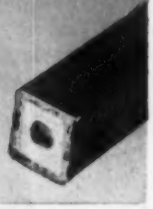

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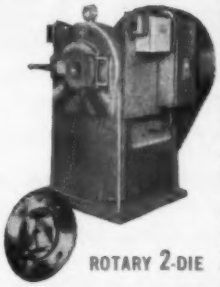

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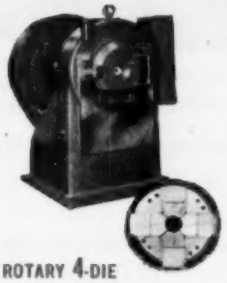

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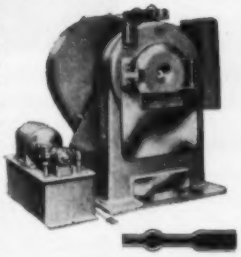

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to a description of various techniques of testing both nuclear components and rocket engines. Also, a brief survey is given of some possibilities for "blue-sky" research in the utilization of nuclear power for propulsion.

In this clear and concise text, the authors have succeeded in their objective of giving the rocket engineer a basis for understanding the problems of reactor design, operation and interaction with the rest of the propulsion system. For the nuclear engineering specialist, the book provides an introduction to one of the most fascinating applications of atomic power.

Geneva '58 Proceedings*

Vol. 10, Research Reactors (548 pages, $18.50), in its description of reactor designs and narration of operating experience, indicates the vitality of the research and engineering test reactor field. The discussions are conveniently grouped according to reactor type, i.e., high-power, low-power, enrichment, moderator, etc. Since this type of reactor is within the capabilities of more countries than are power reactors, the authors of this volume display a wider international representation than do other reactor volumes.

Vol 11, Reactor Safety and Control (550 pages, $15.50) has 61 papers on reactor safety, containment, control and boiling-water reactors—i.e., the papers of sessions A-14, B-13 and B-14a. Most of the titles contain the words "safety" and "containment." But also included are several with titles involving "legal aspects," "ships," "kinetics," "transients," "detectors" and "xenon." More than ⅓ of the papers are from the United States, but the reader with a world-wide curiosity will find some contributions from other countries that have reactors and some from those that do not. He can read about how to build a reactor underground in Norway and how to control the large power reactors of Great Britain. Four papers are from Russia. Other nations that contribute experimental and theoretical papers are Sweden, Belgium, Rumania, West Germany, Portugal, Switzerland, Czechoslovakia, Australia, Japan, France, Canada, India and Brazil.

* Other volumes were reviewed in the July, August and September issues of NUCLEONICS.

Department starts on page 6

delay (if desired, within a few minutes).

3. I feel that, except for special cases, *direct-reading* dosimeters should not be used by persons who are unable to judge the value of the measurements. If, for example, the dose rate reaches a high level for a limited time so that the average dose remains low, unnecessary concern could arise. Where films are used simultaneously, the unavoidable discrepancies between the two results could lead to unjustified distrust in the monitoring program.

—A. BIERMAN
Health Physics Division
Atomic Energy Commission/Laboratories
Rehovoth, Israel

Electron-Energy Determination

Dear Sir:

In the article "Method for Checking Energy of Accelerated Electrons" by Campanile and Wagner in the July 1959 issue of NUCLEONICS, p. 74, it was stated that "It has been found unfeasible to use neutron counters in the photodisintegration-threshold method since these counters are inoperative at these very high photon fluxes." I would like to point out that a paper was presented at the December, 1956, American Nuclear Society meeting by S. L. Ruby and the writer on the use of neutron scintillation counters for the energy calibration of electrons from an accelerator.

The method used was fairly standard. The electron beam was converted to bremsstrahlung with a 0.021-in. gold target. Runs were made with both beryllium and deuterium oxide as the neutron generator. The neutron detector was placed at right angles to the neutron source and was surrounded with paraffin. The neutron detector was a ZnS-boron phosphor of the type described by Sun, Malemberg and Pecjak (NU, July '56, p. 46). The entire success of the method is the result of the detector. The thin layer of the detector discriminates strongly against the X-ray background. The largest pulse from an X-ray in this phosphor is less than half of the voltage of most of the neutron pulses. The detector also has a high (about 20%) efficiency for neutrons. The calibration with deuterium was the most precise with the threshold determined to within ±0.2%.

—C. C. THOMAS, JR.
Atomic Power Department
Westinghouse Electric Corporation
Pittsburgh, Pa.

GCRE Hot Spots

DEAR SIR:

The article, "APDA Introduces Statistical Hot-Spot Factors," which appeared on p. 92 of the August issue, is very interesting. The following comments may also be of interest.

The statistical approach described in the article has been independently used by Allis-Chalmers' Nuclear Power Department–Washington to predict fuel temperatures for the Experimental Gas-Cooled Reactor, which is being designed for Oak Ridge. The method has also been extended to predict the probable rate of failure of fuel elements during operation. As pointed out by Bill Farmer in the article, Allis-Chalmers does not use the statistical approach in analyzing its water-cooled reactors. However, in the case of gas-cooled reactors, the low heat capacity of the coolant and large temperature rise through the reactor lead to a situation in many ways similar to that which obtains with liquid-metal cooling and a number of factors of comparable magnitude must be combined. The statistical basis of combination is believed to be more logical and more useful than the conventional method.

The first such analysis of fuel temperatures in the Experimental Gas-Cooled Reactor was reported by J. K. Davidson et al. in ACF-GCPR Study No. 3-282, "Prediction of Fuel Element Failures, Steady State and Accident Conditions, Gas-Cooled Power Reactor," issued February 26, 1959, copies of which are available. A paper on the subject by J. K. Davidson and L. H. Devlin is to be presented at the November ANS Meeting in Washington. The statistical method of combining hot-spot and hot-channel factors was developed from that which is described briefly in pages 442–446 of Bonilla's "Nuclear Engineering."

It seems to me that the important questions regarding the use of the statistical method are the following: (1) Is it more logical than the conventional method? (2) Is it more useful?

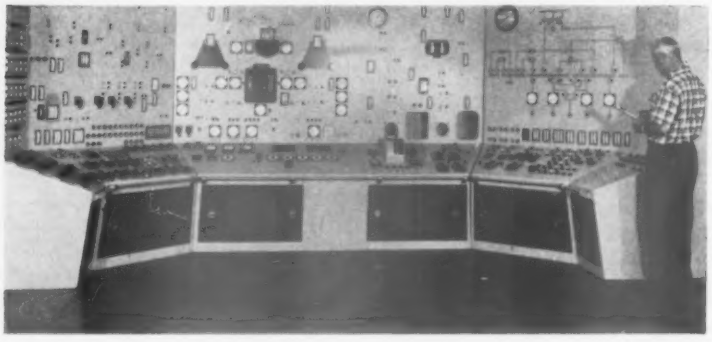
Regarding the first question, the statistical method appears to be more logical because it recognizes a fundamental fact of life—it is possible mathematically to relate large numbers of events that are causally unrelated. This argument carries different weight with different people. Many scientists, and some engineers, prefer for intellectual and aesthetic reasons to base their analyses upon those models that are known to conform closest to nature's operation, even though lack of basic information makes the final answer as inaccurate as that obtained by use of a less appropriate model.

The second question is of general interest, and, in the case of the Experimental Gas-Cooled Reactor, the answer is affirmative. The report mentioned above computes the probable distribution of fuel-cladding temperatures at each location in the reactor. The exposure at each location is known from the fuel-programming scheme. The stress in the cladding is calculated from the fission-gas pressure, which in turn is known from the fuel exposure and fractional fission-gas release. These probable temperatures and calculated stresses are then combined with conservative criteria of fuel failure to predict a failure rate.

The analysis is particularly important in the case of the Experimental Gas-Cooled Reactor. This reactor was designed by Allis-Chalmers with the capability to detect and replace defective elements under power so that the fuel exposure can be pushed to the point that the failure rate is the economic optimum. While the analysis cannot "prove" anything, it does provide very useful information. The knowledge that a maleficient concatenation of events (whose likelihood of occurrence during reactor life approximates that of Jean's monkeys producing the volumes of the British Museum) could bring an individual fuel element to a temperature of 2,200° F does not constitute useful information to most reactor designers. On the other hand, a quantitative estimate of the probability that a stated number of elements will exceed 1,500° F is useful.

In addition, a quantitative estimate of the probability that the rate of fuel failure will not be so low as to be wasteful of the investment in fuel and yet will be low enough to fall within the capabilities of the machine is a useful piece of information in fixing design objectives. Further, when the reactor goes into operation, the prediction of fuel failure rate provides the operator with a useful basis for evaluating the failure rate that is encountered in practice.

—W. F. BANKS, Project Manager
Allis-Chalmers Manufacturing Company
Washington 11, D. C.



Reactor Console for the *Savannah* . . .

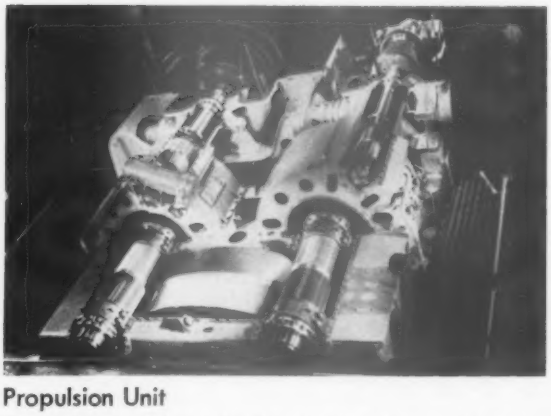
Over 480 control and indicating items are incorporated in the main console built by Bailey Meter Co., Cleveland 10, Ohio. These include: 20 flow indicators, 15 level indicators, 45 pressure indicators, 35 temperature indicators, 55 meters, 31 valve selector switches, 60 selector switches and 120 push buttons.

. . . and Its Simulator

The simulator, built by Westinghouse Electric Co., Pittsburgh 30, Pa., is a key tool in the crew training program already in progress. An analog computer is the central element and 54 switches enable simulation of various malfunctions.

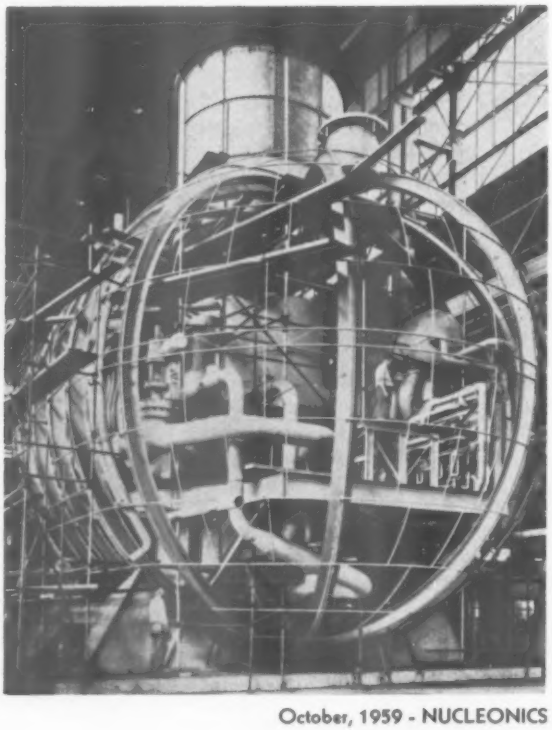
Nuclear Gear for NS *Savannah*

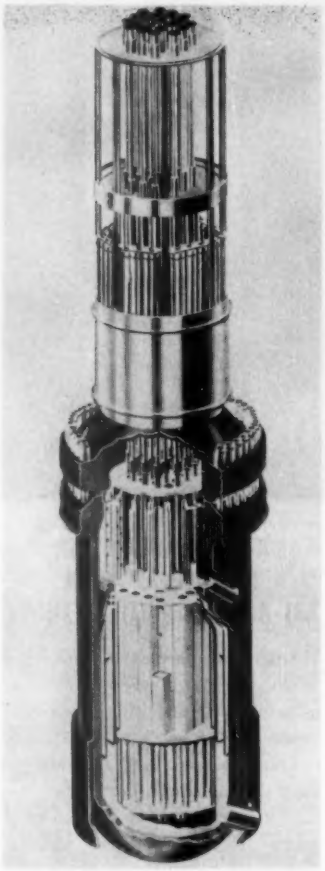
The world's first nuclear-propelled merchant ship will be powered by an advanced pressurized-water reactor. Prime contract with AEC for design and manufacture is held by The Babcock and Wilcox Co. which has called on more than 30 principal vendors to supply major components and subassemblies such as are shown here.



Propulsion Unit

The main propulsion unit (above) is like those used in conventional steam-turbine-driven ships but special features have been incorporated. The main turbines are designed to develop 22,000 shp using 430–700-psia saturated steam. Excessive moisture is withdrawn from the turbines to prevent erosion. If reactor power is lost, diesel generator powers 750-hp electric "take-home" motor clutch-mounted on the reduction gear. Condenser tubes are welded to tube sheet to keep salt water from the steam generator.—DeLaval Steam Turbine Co., 802 Nottingham Way, Trenton 2, N. J.



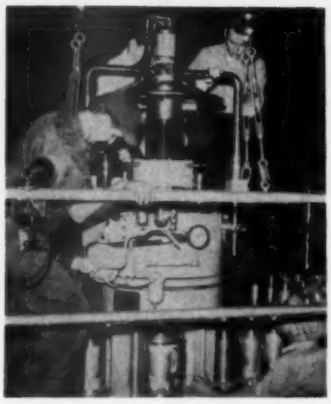


Pressurized-Water Reactor

Light water at 1,750 psia moderates and cools the reactor. Core has 32 fuel elements each with 164 fuel rods that contain a total of 8,060 kg of UO_2 enriched to an average of 4.4% in U^{235}. Rods have 0.5 in. dia with 0.035-in.-thick walls. Conversion ratio is expected to be ~0.4. The 21 boron-stainless-steel cruciform control rods are 8 in. wide and 0.375 in. thick. Core life at 63.5 Mw is calculated to exceed 700 days.—The Babcock and Wilcox Co., 161 E. 42nd St., New York 17, N. Y.

← Nuclear Power Plant Mockup

Full-scale mockup of the nuclear power plant (left) is 70 ft long and 55 ft high. Crew can move about in this "plant" to fulfill simulated maintenance and repair operations as they will later aboard ship. Design can also be checked for exact clearances prior to shipboard installation.—New York Shipbuilding Co., Camden, N. J.



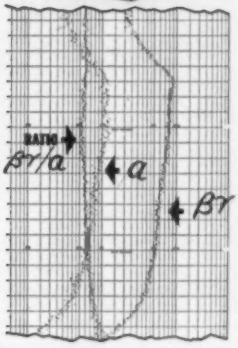
Tensioner for 350-lb Bolts

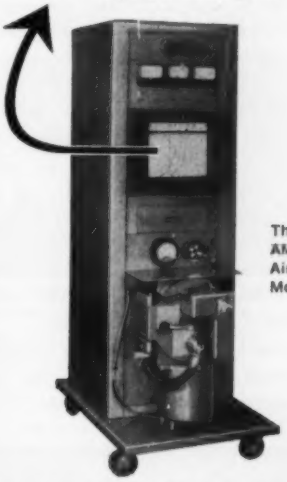
Powerful hydraulic-jack-type stud tensioner (above) was designed to secure the 45-ton top closure of the nuclear reactor. The precision-controlled device easily tightens or loosens the 48 stud bolts that are 5 ft long, 5 in. in diameter and weigh 350 lb. Two or three evenly spaced tensioners will be used simultaneously.—Diamond Power Specialty Corp., Lancaster, Ohio.

Eight Miles of Tubing

The two heat exchangers required 43,704 ft of ¾-in. seamless, cold-drawn stainless-steel tubing (above). This was cut into 1,624 tubes that were bent on a special former; 61 different bends were made. Special procedures included ultrasonic inspection, hydrotesting at 2,880 psi, liquid penetrant testing and air and alcohol cleaning.—The Babcock and Wilcox Co., 161 E. 42nd St., New York 17, N. Y.

This Air Monitor Solves the Natural Radon Progeny Problem





The New AM-33R Air Monitor

The AM-33R is First to Provide *Direct* Identification of Long Half-Life Emitters

Due to natural radon progeny, identification of long half-life emitters with ordinary monitors means a delay of five hours or more, and requires multiple detectors. Now, with the new AM-33R air monitor, the presence of these emitters can be identified directly, and almost immediately—with a single detector.

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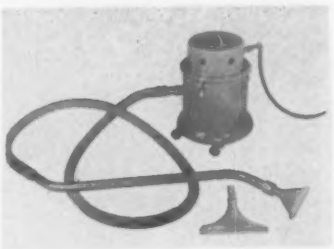
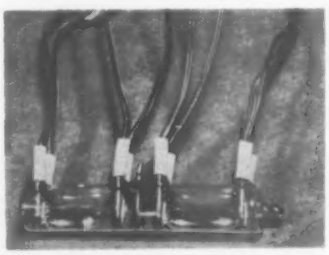


Air-Powered Vacuum Cleaner

Any compressed-air source will operate the Jet Syphon, an industrial vacuum cleaner. The 29-lb unit creates a powerful suction for fast wet-or-dry pickup and thorough cleaning. The cleaner can safely handle radioactive dust as well as combustible dust such as magnesium.—Laukhuff-Pratt Mfg. Co., 3097 W. Mill Rd., Milwaukee, Wisc.

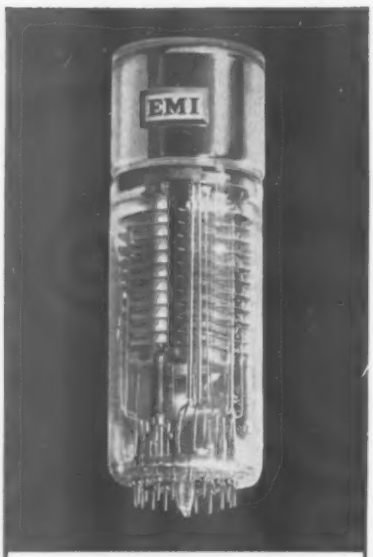


One-Way Mercury Switch

A momentary wipe contact is achieved tilting the one-way mercury switch (above) 10 deg or more in one direction. Returning the switch to its original position breaks the contact. A variety of circuit arrangements are achieved by using this basic orifice principle and inserting additional electrodes. Standard-size switch, $<2\frac{3}{4}$ in. long and $<\frac{1}{2}$ in. in diameter, is capable of carrying 5 amp at 115 v and inrush overloads of up to 10 amp.—American Designed Components, Inc., Jericho, L. I., N. Y.

Teflon Spargers and Liners

Type-LS sparger is constructed of laminated Teflon-and-glass fabric with a steel reinforcing tube built inside the wall. The reinforcing tube, which provides the necessary bend strength required under severe agitation conditions, extends from just under the connector-flange flare to just above the sparger holes. Teflon nozzle liners are designed for use in reactor vessels, condensers and pumps. Also the lubricating properties of Teflon reduce or elimi-



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The cathode embodied in Tube Type 9558B gives a high quantum efficiency of between 15 and 20% in the blue region (at 4,200 A°), and an extended red response up to 8,500 A°, while the dark current remains very low. This tube is especially suitable for spectrometry (particularly flame spectrometry), for scintillation counting with materials such as caesium iodide, and for scintillation counting of C^{14} and H^3.

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Number of stages	11
Overall voltage	1700
Overall sensitivity A/L	200
Dark current μA	0.003
Photosensitivity μA/L	100

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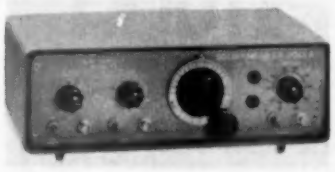
nate problems of erosion-corrosion at the entry side of heat-exchanger tubes. Shock resistance of the liners gives added protection necessary for lining fragile nozzle openings of glass- or ceramic-lined vessels.—Resistoflex Corp., Roseland, N. J.

Counting-Rate Meters

Seven new models of counting-rate meters are available in various combinations of linear, logarithmic and difference indications of counting rate. Model CRM-2 is linear with 10 ranges from 1×10^2 to 3×10^6. Model CRM-3 provides logarithmic coverage over a six-decade range to 10^7 cpm. Model CRM-4 simultaneously provides the linear and log indications of the instruments above. Models 2CRM-2 and 2CRM-3 are dual counting-rate meters and incorporate two linear or two logarithmic circuits, respectively. Models 2CRM-2D and 2CRM-3D are log dual-differential counting-rate meters with a difference amplifier added enabling the operator to observe the difference in counting rate between the two primary channels.—The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

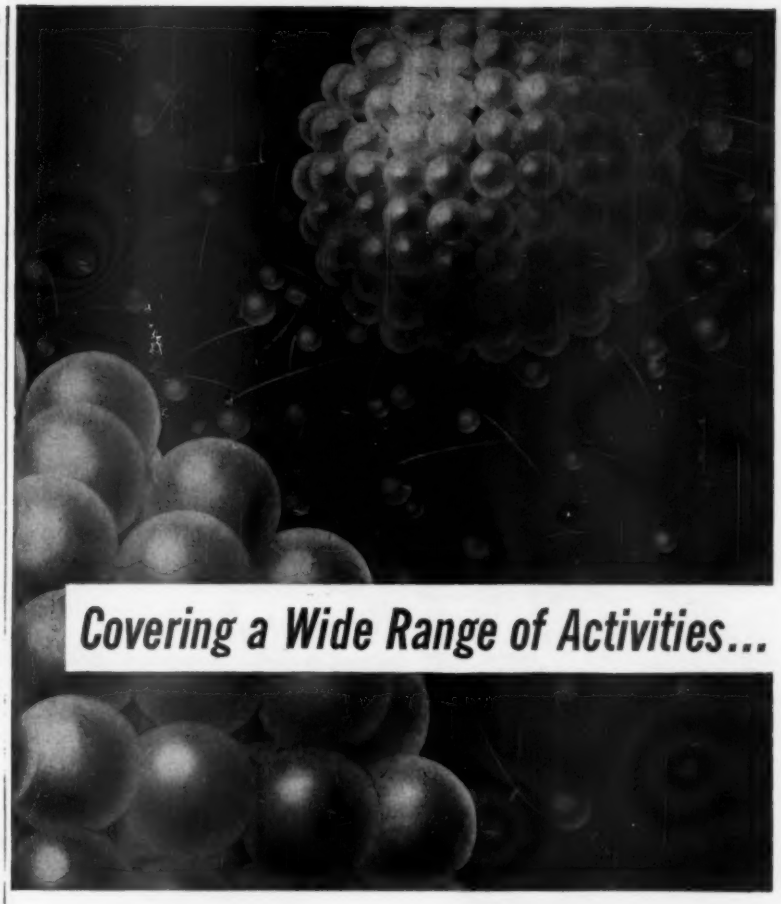
Pulse Generator

Model PPG-1 pulse generator can calibrate both single- and multi-channel pulse-height analyzers. The fast-rising, exponentially decaying pulses simulate the output of most radiation detectors. The low-level pulse reduces the high-level pulse by factors of 1, 10, 100 or 1,000. The latter is attenuated by a factor of 10 when the low-level pulse is attenuated by 10 or 1,000 and is unaffected on the 1 or 100 attenuator positions. Rise time is continuously variable from 50 mμsec to 1 msec with output loaded to 50 μμf.—The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.



Transistorized Pulser

Completely transistorized pulse generator (above) operates on battery or a-c lines and requires less than 2 watts. Pulse width can be varied from 0.5–100 μsec with a rise time of <0.1 μsec. Repetition rate can be continuously



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a filter man's thinking

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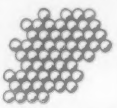

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Department starts on page 118

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Fast Sampling Oscilloscope

Ultrahigh-speed oscilloscope (above) features a linear 5-in. cathode-ray-tube display, rise time above 400 μμsec, sensitivity better than 3 mv/cm and sweep speeds up to 40 μμsec/cm. The instrument employs a sampling technique and takes amplitude samples from successive, unamplified repetitive pulses. Each sample is slightly later than the preceeding one. The samples, rather than the pulse, are amplified.—Lumatron Electronics, Inc., 68 Urban Ave., Westbury, N. Y.

Solid-State Printer

Model 400C-T solid-state printer is compatible with all makes of solid-state counting equipment having a 4-line 1-2-3-4 binary-coded decimal output. The printer uses transistorized plug-in drivers for each digit. The plug-in modules can be changed to match a variety of outputs from transistorized equipment. Features also include 4 lines/sec printout, no stepping switches, parallel entry and standard 6-digit printout.—Computer-Measurements Co., 5528 Vineland Ave., No. Hollywood, Cal.

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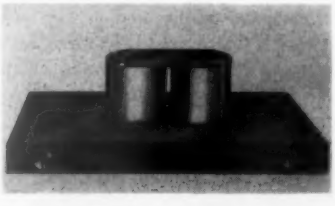
Limit-Switch–Stop

Continuously adjustable limit-switch–stop features a single exterior range-adjustment screw permitting rapid adjustment to any angular rotation from 0 to 25 turns. The switch is actuated at either end of shaft travel just prior to contact with nonlocking limiting stops. Torque capacity at end stops is 40 oz-in.—Precision Mechanisms Corp., East Meadow, N. Y.



Thermoelectric Junction

Type TA-11 thermoelectric junction (above), designed for application in cooling, heating, power generation and/or dynamic heat transfer, uses *n*- and *p*-type bismuth-telluride alloys in crystalline form. Temperature differences of up to 70° C can be obtained; the cold-junction temperature is below 0° C in this instance.—Ohio Semiconductors, Inc., 1035 W. Third Ave., Columbus 8, Ohio.

High-Vacuum Pumps

Oil diffusion pumps in 2- and 10-in. models have greater capacity, smaller size than older models. Speed of 2-in. model is 80 l/sec at 0.1 micron Hg, of 10-in. model is 2,600 l/sec with an ultimate pumping pressure of 5×10^{-7} mm Hg. A 300-cfm, 2-stage mechanical booster pump provides very high pumping speeds over a 1 mm–0.5 micron range. A Roots-type blower and rotary gas ballast unit are connected in series and independently driven with induction motors.—NRC

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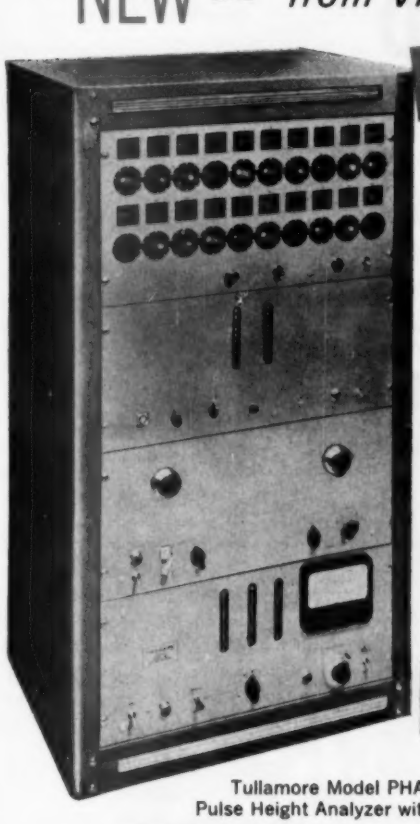

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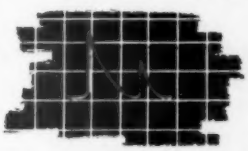

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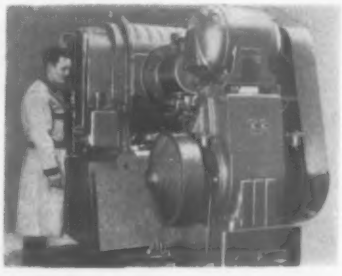
PRODUCTS & MATERIALS

Department starts on page 118

Equipment Corp., 160 Charlemont St., Newton, Mass.



King-Sized Vacuum Pump

King-sized Model 1713 mechanical booster vacuum pump (above) has 6370-cfm displacement. The pump has a two-stage high-speed system consisting of a high-capacity Roots-type dry blower backed by a gas-ballasted rotary piston-type mechanical vacuum pump. This combination offers high pumping rates in the pressure range from 1 mm to 10 microns.—F. J. Stokes Corp., 5500 Tabor Rd., Philadelphia 20, Pa.

High-Vacuum System

Ultrahigh vacuum system can exceed 1×10^{-9} mm Hg in a stainless-steel chamber 12-in. dia by 18-in. high. The chamber is equipped with two 2-in. windows, rotary-motion and electrical feed-throughs. The work chamber is enclosed in a mild-steel outer chamber that has two corresponding 2-in. windows and is fitted with heating elements, radiation shielding and water cooling coils.—Kinney Mfg. Div., The New York Air Brake Co., 3529 Washington St., Boston 30, Mass.

Liquid Scintillation Counter

LCS-10 is a low cost semiautomatic liquid scintillation counter designed for precision analysis of low energy beta emitters. System consists of open-top freezer and 4-ft instrument console. Sample changer holds forty 20-ml glass vials; all samples can be counted without opening the freezer. An additional 40 samples can be stored in the freezer.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Ceramic Insulation

Radiation-proof high-temperature ceramic insulation is completely boron- and cobalt-free with a resulting capture cross section of less than 20 barns. The material, which has a temperature rating of 1,000° F for continuous operation, has been coated on wire 10-mils thick or thicker. Conductor materials have included aluminum, nickel-clad copper, Chromel, Alumel and Constantan.—Technical Industries Corp., 389 N. Fair Oakes Ave., Pasadena, Cal.

Metallographic Samplemover

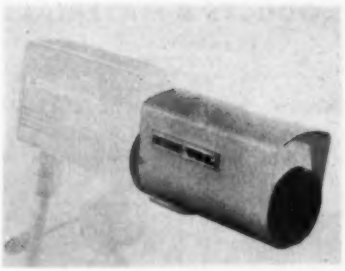
Used for grinding and polishing metallographic specimens, the samplemover accommodates up to six specimens simultaneously. By means of adapters, specimens of different diameter can be processed at the same time. A liquid brake is used to assure proper relative movement of the disc and sample.—William J. Hacker & Co., Inc., P.O. Box 646, West Caldwell, N. J.

Duplex Pump Controls

Type-DP duplex pump controls permit two pumps to operate either individually or in conjunction depending upon the pumping rates required. Remote motor control is provided with such pilot devices as pressure switches, float switches and maintained-contact push buttons.—The Arrow-Hart & Hegeman Electric Co., 123 Hawthorn St., Hartford, Conn.

Closed-Circuit Television

Radioactive fuel elements can be observed with a closed-circuit television system (above) as they are inserted or withdrawn from the core of the Sodium Reactor Experiment. A miniature camera, $2\frac{1}{2}$-in.^{2} by $7\frac{1}{2}$-in. long is positioned inside the shielded cask that transfers the fuel elements. An element is pulled through an indexing ring with a small window in the side for the TV pickup. Twelve small lights within the indexing ring provide illumination. The camera has a 16-mm f/2.5 prefocused lens.—Photo Research Corp., 837 N. Cahuenga Blvd., Hollywood 38, Cal.

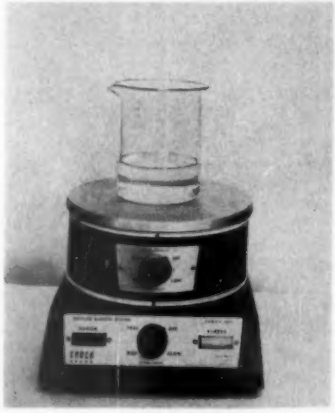


Auto-Zoom Lens

The auto-zoom lens (above) for industrial TV cameras enables a camera to operate with a continuously changing field of view. Equivalent lens range is 30–150-mm. Zoom, iris and focus adjustments are controlled by three separate d-c motors and have varying adjustment rates. The control motors, shielded to minimize radio interference, are regulated by a series of microswitches. The lens is color-corrected and has a speed of f/2.7 from 30 to 120 mm and better than f/3.5 from 121 to 150 mm.—KIN TEL Div. of Cohu Electronics, Inc., Box 623, San Diego, Cal.

Tantalum-Tipped Thermowells

Tantalum's heat-transfer characteristics enable new thermowells to respond promptly to changes in bath temperature. They can be used with glassed-steel process equipment and are resistant to damage from either thermal or physical shock. Two thermowells $\frac{3}{8}$ in. and $\frac{1}{2}$ in. i.d. with rated external pressures of 400 and 270 psi respectively are available.—The Pfaudler Co., 1090 West Ave., Rochester, N. Y.

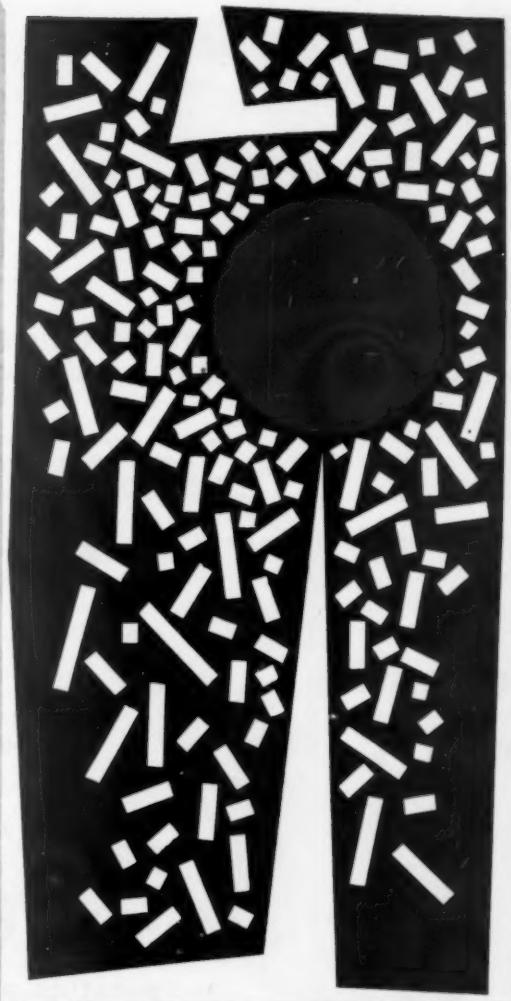


Hotplate Magnetic Stirrer

Electric hot plate combined with variable-speed magnetic stirrer (above) can be operated as an independent stirring unit, as a heating plate or as both simul-

Experimentation in nuclear particle motion and energy—one of our many probes into the future.

Original painting by Oli Sihvonen, Taos, N. M.



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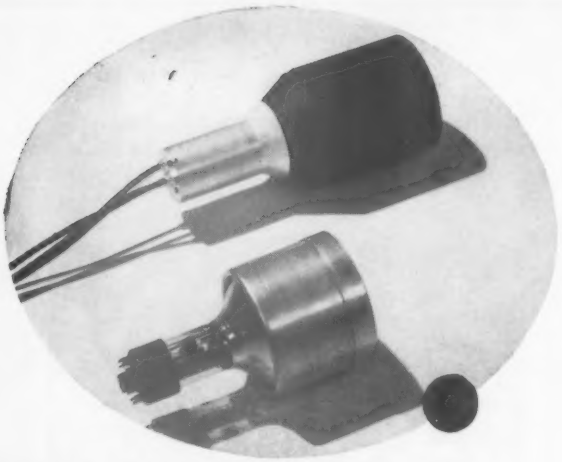

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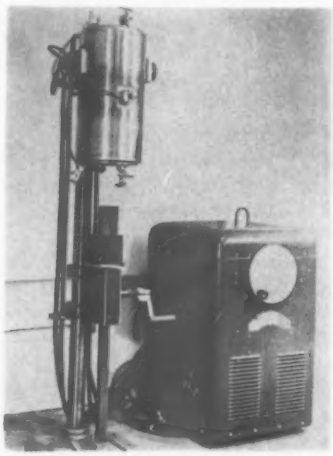
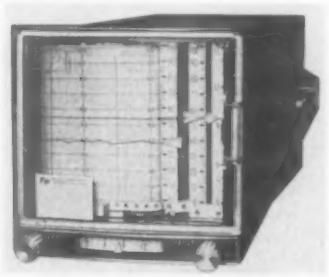
taneously. Stirring bars are available in various sizes.—Central Scientific Co., 1700 Irving Park Rd., Chicago, Ill.



High-Temperature Furnace

Resistance furnace for laboratory use (above) operates up to 5,000° F and has inert-gas atmosphere, graphite heating element and carbon insulation. Readily modified standard unit has a 4-in.-dia heating chamber that is 8 in. high. Tubes at top and side of the furnace allow sighting for temperature readings and automatic control.—Curtiss-Wright Corp., Santa Barbara Div., P.O. Box 689, Santa Barbara, Cal.



Recorder-Controller

Mark III 4-in. strip-chart recorder-controller (above) has an inking system that operates a month without refill. The pen mechanism provides a bolder, more uniform line over the entire chart width. The instrument also features a flip switch for reversing controller action. Large control knobs permit operation with gloves on.—Fischer and Porter Co., 143 Jackson Rd., Hatboro, Pa.

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3mV	full scale
10mV	full scale
30mV	full scale
100mV	full scale
1V	full scale
3V	full scale
10V	full scale
30V	full scale
100V	full scale

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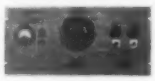

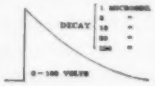

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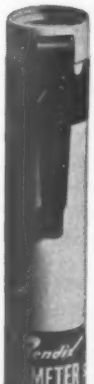

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LITERATURE AVAILABLE

Radioisotopes. "How to Evaluate an Analytical Method with Radioisotopes." 4 pp.; Nuclear-Chicago Corp., 229 W. Erie St., Chicago 10, Ill.

"Labeled Compounds." 24 pp.; Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

Flame spectrophotometry. Bulletin 753, 1 p.; Beckman, Scientific and Process Instruments Div., 2500 Fullerton Rd., Fullerton, Cal.

Scalers, ionization chambers. Bulletins 144, 164, 166, 6 pp.; Technical Associates, 140 W. Providencia Ave., Burbank, Cal.

Spectrographic chemical equipment, laboratory services. 36 pp.; National Spectrographic Laboratories, Inc., 6300 Euclid Ave., Cleveland 3, Ohio.

"Isotope Manipulators." 4 pp.; Nuclear Research Applications Ltd., Emefco House, Reigate, England.

"Radioisotopes in Industry, Research, Medicine and Education." 28 pp.; Atomic Accessories, Inc., 244–02 Jamaica Ave., Bellerose 26, N. Y.

"Chromatographic Materials." 8 pp.; Research Specialties Co., 200 S. Garrard Blvd., Richmond, Cal.

Solenoid and spray valves. 4 pp.; Automatic Switch Co., 50–56 Hanover Rd., Florham Park, N. J.

Magnetic amplifier systems. Bulletin S-963, 8 pp.; Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y.

"Electrostatic Generators." 6 pp.; Sorensen & Co., Inc., Richards Ave., So. Norwalk, Conn.

Ten-digit direct-readout tube. 2 pp., and glow-tube scaler, 2 pp.; Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Isotope casks and containers in standardized sizes. 4 pp., The Edlow Lead Co., 729 Bank St., Columbus, Ohio.

Microfilter. 6 pp.; Millipore Filter Corp., Bedford, Mass.

Automatic X-ray spectrograph. 8 pp.; Philips Electronics, Inc., Instruments Div., 750 Fulton Ave., Mount Vernon, N. Y.

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INDUSTRY NOTES

• **Anton Electronics Laboratories,** Brooklyn, is being "spun off" (i.e., dropped as a subsidiary) by its parent firm, U. S. Hoffman Machinery Corp. Subject to Hoffman stockholder approval, Anton will be merged with Inter-Continental Manufacturing Co., Garland, Tex., another Hoffman subsidiary, to form **Anton-Imco Electronics Corp.**

• **Tracerlab** has been on a 55-hour week since early August to catch up with a record, $3.5-million order backlog. Despite—and possibly because of—the high level of business—Tracerlab suffered a loss of $227,000 for the first half of 1959; $154,000 of the loss was laid to increased development and sales effort.

• **Mahony-Troast Construction Co.,** Clifton, N. J., has begun construction of two buildings to house a research reactor and a radioactive materials laboratory at the Sterling Forest, N. Y., research center of **Union Carbide Nuclear Co.** Completion target is the fall of 1960. The AMF-built, 5-Mw reactor to go into the Center has been ready for some time.

NEW FIRMS. Three groups of Oak Ridge, Tenn. scientists have established nuclear firms: **Chemical Separations Corp.,** P.O. Box 149, Oak Ridge, Tenn., for contract research and production of ion-exchange and solvent-extraction units; **FairPort Instruments, Inc.,** 270 Midway Lane, Oak Ridge, to develop and manufacture electronic instruments for nuclear measurements; and **Tennessee Technical Translators,** P.O. Box 322, Oak Ridge, to do technical literature work (translations, literature searches, special reviews). . . . **Radon Research Foundation,** Boulder, Mont., has been chartered to do research on uranium, thorium and other radioactive minerals. . . . **U. S. Shielding Corp.,** White Plains, N. Y., has organized a group of engineers with radiation-shielding experience to design and build fallout shelters for residential, commercial and government buildings in the New York area. . . . **Nuclear Decontamination Corp.,** Apollo, Pa., for decontamination of clothing, has been formed by Nuclear Materials and Equipment Corp. of Apollo and Iron City Industrial Cleaning Corp. of Pittsburgh; simultaneously Numec has inaugurated a decontamination service of its own for equipment and other non-clothing items. Nuclear Decontamination will operate a fleet of trucks to the northeast and south to the state of Georgia.

EXPANSIONS. A distribution, installation and service facility has been established by **Baird-Atomic** in Kleve, West Germany, for its line of spectrographic instrumentation. . . . **Hughes Aircraft** has created a nuclear electronics laboratory—as a new department—to direct the firm's growing nuclear activities. . . . **Foote Mineral Co.** has broken ground for a $2.2-million research and engineering building near Exton, Pa. . . . **American Metal Products** expects interim operation in December and full operation in 1960 of a new research, engineering and development center at Ann Arbor; the facility will serve AMP's growing emphasis on high-temperature materials for nuclear and missile applications. . . . **Victoreen Instrument** has acquired an interest in Federal Manufacturing and Engineering Corp., Garden City, N. Y.

FINANCIAL. **Beryllium Corp.** asked its stockholders late in September to okay a 2-for-1 stock split and to increase authorized common stock to 3-million shares from 1.2-million; Beryllium reported sales of $10,720,462 and earnings of $1.29 per share for the first six months, compared with $6,658,697 in sales and 9 cents/share in earnings for the same period last year. Sales objective this year, the firm said, is $20-million. . . . **National Research Corp.** reported a loss of $100,534 for the first six months but said it looked for a substantially better showing in the second half of the year.

NEW BUSINESS. Under several Navy contracts totaling $1,250,000, **Specialty Electronics Development** has gone into production with an ultrasensitive radiation detector; the firm has also completed development of a personal dosimeter—recording exposure cumulatively—and expects to market 5,000,000 to the armed forces within two years. . . . **Gilliland-NRI** (NU, Sept. '59, 157) has sold Franckenstein measuring projectors—for $100,000 each—to Duke and Yale Universities. . . . **Nuclear Systems div. of Budd Co.** has delivered a Hotrodder radiation unit to Shell Chemical Corp. for use at its synthetic rubber research center; the unit is designed to contain 20,000 curies cobalt-60.

NUCLEAR CAMPUS

• AEC suffered a serious blow to its training-reactor grants program when Congress appropriated only $1.8-million of the $3.1-million requested for grants during the current fiscal year (ending June 30, 1960). The program has been the major force for purchase of reactors up to 10-kw for campus installation. Congress gave AEC another $2-million for transfer to the National Science Foundation for support of campus reactors for research.

• AEC grants in support of nonreactor facilities have gone to two schools: 1. The Univ. of North Carolina was given $98,000, primarily for the purchase of a 2-Mev Van de Graaff accelerator. Delivery is expected this month. 2. Some $100,000 worth of uranium (2½ tons) and plutonium-beryllium (80 gm) has been lent to Stevens Institute of Technology—without charge—to fuel an underground subcritical reactor now under construction.

• U. S. Radium Corp. has launched an apprentice training program at its Bloomsburg, Pa., plant designed to create a manpower reservoir for its growing nuclear operations. Pennsylvania high school graduates and college students on vacation are being given intensive training courses.

COURSES. Beginning in 1960, the Oak Ridge Institute of Nuclear Studies will offer a revised curriculum in **radioisotope training.** Four courses will be offered: **basic radiation physics** (two weeks); followed by simultaneous courses in **radioisotope research techniques** and **industrial radioisotope techniques** (two weeks each); and, finally, **special industrial and research techniques** (two weeks). Thus, over a six-week period as many as three courses will be available, although only 24 applicants will be accepted for the final course as against 72 for the basic course.

Metals Engineering Institute, home study division of the American Society for Metals, is offering **metals for nuclear power.** Contact MEI, Dept. FS-3, 7301 Euclid Ave., Cleveland 3, Ohio.

New York University-Bellevue Medical Center Post-Graduate Medical School is offering **introduction to radiological health** (Oct. 12–23), **radiological health laboratory** (Oct. 26–Nov. 6), **radiochemical analysis** (Nov. 9–20), **medical and public health control of ionizing radiation** (March 7–18) and **radiation hygiene measurements** (Apr. 18–May 13). Contact the dean, 550 First Ave., N. Y. 16, N. Y.

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NEWSMAKERS

Paul Schall, Jr., chief of radioisotope and radiation research at Battelle Memorial Institute, has left Battelle to join the Hallam reactor program at Atomics International. The Hallam sodium-graphite reactor is being designed for food-processing capability, as well as a source of heat for conversion to electricity.

H. R. Schmidt has been named manager of the chemical laboratory at Knolls Atomic Power Laboratory. He succeeds **W. M. Cashin,** manager of KAPL's materials development group.

New manager of the Metals & Controls div. of Texas Instruments is **E. O. Vetter,** TI vice-president. Vetter succeeds **C. J. Thomsen,** who has returned to TI headquarters in Dallas as vice-president, control and finance. Meanwhile, an Oak Ridge scientist, **Roger C. Waugh** of the Metallurgy div., has joined M & C Nuclear as project engineer for industrial fuel elements, he will help develop fabrication and production techniques.

Two key posts have been filled at Picker X-Ray Corp.: **John M. Gleeson** has been elected vice-president and **Donalee L. Tabern** has been appointed director of radioisotope education in the Nuclear div. Gleeson joined Picker in 1942, was elected secretary in 1949 and a director in 1950. He was treasurer and assistant general manager of Westinghouse X-Ray Corp. before he joined Picker. Tabern retired as head of the Radioactive Pharmaceutical div. of Abbott Laboratories earlier this year (NU, June '59, 149). He founded the Abbott radiopharmaceutical program shortly after World War II.

Gleeson

Tabern

Two new staffers at Atomic Accessories are: **Jim Lunny,** formerly of Nuclear Corp. of America, who has opened a Detroit office for AA; and **Ed Kerzner,** formerly of Curtiss-Wright, who has been named administrative assistant to President Jack Carlin.

Robert C. Koch, a specialist in activation analysis, has been named assistant manager of the Chemistry dept. at Nuclear Science and Engineering.

A committee of four industrialists and one educator—chaired by **Lauchlin M. Currie** of Babcock & Wilcox—has been established by the Engineers Joint Council and the associated groups sponsoring the annual Nuclear Congress. The committee will lay out objectives of the Congress, decide policy issues and handle relations with other organizations. Two former sponsors of the annual event—American Nuclear Society and Atomic Industrial Forum—recently pulled out (NU, June '59, 28), necessitating a reorganization. Currie's comembers on the new Congress committee are: **John R. Dunning,** Columbia Univ.; **George E. Holbrook,** du Pont; **Wilbur E. Kelley,** Associated Nucleonics; and **C. Rogers McCullough,** Monsanto Chemical and chairman of the Advisory Committee on Reactor Safeguards to AEC. General chairman of the 1960 Congress (April 3–8 at New York's Coliseum) is **Clarke Williams** of Brookhaven; program chairman is **E. B. Gunyou** of Curtiss-Wright.

Currie

Verne B. Lewis has been given a year's leave from his post at AEC's Hanford Operations Office (assistant manager for administration) to serve with the Brookings Institute on a program of executive development for federal officials. At Hanford Works, operated for AEC by GE, **Raymond L. Dickman** has been named manager of a new section—manufacturing—in the Irradiation Processing dept.

A veteran radiochemist—**Peter Viet Zuan Phung**—has been named senior research analyst on the management sciences staff of Broadview Research Corp.; he will concentrate on operations research and radiochemistry.

Richard H. Graham, secretary to the Advisory Committee on Reactor Safeguards for the last two years, has joined

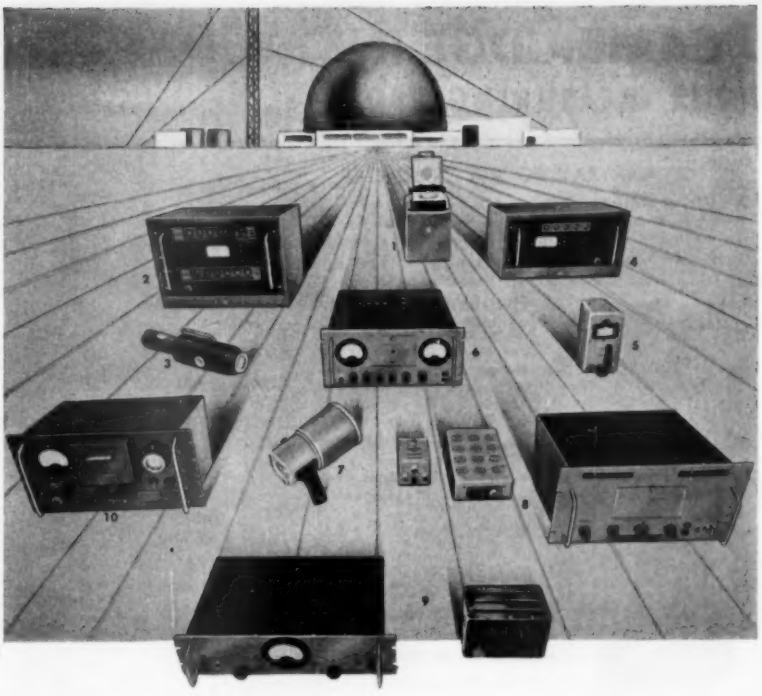
General Electric's Atomic Power Equipment dept. as consultant for product planning.

Elizabeth Bush and **Paul R. Klein** have joined the research and development staff of Nuclear-Chicago. Miss Bush joined N-C from the Univ. of Illinois Medical School; she will work on detector development. Klein left Joseph Kaye & Co. to direct N-C's Physics dept.

Kenneth Street, deputy director of Lawrence Radiation Laboratory, has been appointed professor of chemistry at the Berkeley campus of the Univ. of California, which runs Lawrence for AEC. A reorganization at Lawrence brought these changes: **Harold Brown** succeeds Street; and **Gerald Johnson, Theodore Merkle** and **Duane Sewell** were named associate directors. Johnson will supervise Weapons Test Operations and the Plowshare Program; Merkle will direct Project Pluto (nuclear ramjet); and Sewell will supervise support activities for Lawrence programs.

Nuclear Materials and Equipment Corp. has added four people to its staff: **Harold J. Garber,** formerly of Westinghouse's Atomic Power Dept., project director of plutonium work at Numec for AEC; **Lewis J. Jones,** formerly of Bettis, metallurgy engineering on plutonium; **Eber K. Halteman,** also formerly of Bettis, physics; and **Arthur M. Weis,** formerly of Curtiss-Wright, manager of customer service and contracts.

Oak Ridge National Laboratory has supplied the manpower for three new firms in the Oak Ridge area (*see p. 128*). **Frank Porter** and **Ed Fairstein,** instrumentation specialists, have left the lab to create FairPort Instruments—a nuclear-instrument firm. **Charles W. Hancher,** a chemist, is heading up a group of past and present ORNL employees under the name Chemical Separations Corp., available for equipment and research in the field. **Francois Kertesz,** also a chemist, has established Tennessee Technical Translators—to be staffed by ORNL employees with both technical and linquistic talents. Kertesz's partners in the venture include **J. Lewin,** engineer, **S. Rimshaw,** radiochemist and **G. Watson,** physical chemist. **Mrs. R. Jermain** of AEC's technical information group, will collaborate on nongovernment work.



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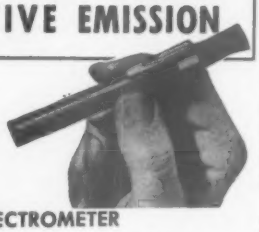

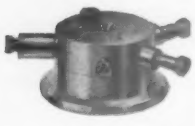

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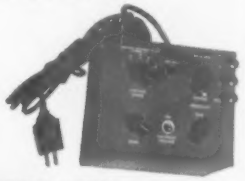

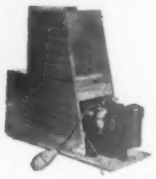

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Oct. 15–16—Radiation Effects Symposium of Glass Div., American Ceramic Society, Galen Hall, Pa. Contact Norbert Kreidl, Bausch and Lomb Optical Co., Rochester 2, N. Y.

Oct. 20–21—Symposium on Reprocessing Nuclear Fuels, sponsored by AEC, Richland, Wash. Review of current technology for management and technical personnel. Contact J. T. Christy, Hanford Operations Office, USAEC, Richland.

Oct. 26–28—Third Conference on Analytical Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn. Contact C. D. Susano, Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn. (papers), or Tom Woods, Mgr., Mountain View Hotel, Gatlinburg (accommodations).

Nov. 2–6—Joint Meeting of Atomic Industrial Forum and American Nuclear Society, Washington, D. C. (*Sheraton Park*). AIF's annual meeting scheduled first three days (Nov. 2–4), ANS' semiannual meeting begins third day (Nov. 4–6). For AIF meeting contact AIF, 3 E. 54th St., N. Y. 16, N. Y.; for ANS meeting contact ANS, 86 E. Randolph St., Chicago 1.

Nov. 2–6—41st National Metal Exposition and Congress, sponsored by American Society for Metals, Chicago (*International Amphitheatre, several hotels*). Includes symposium on the rare earths and related metals Nov 2–3 (*Sherman*). Contact A. K. Murray, 1059 Leader Bldg., Cleveland 14.

Nov. 4–6—National Automatic Control Conference, Dallas (*Sheraton*), sponsored by Institute of Radio Engineers. Also participating: American Institute of Electrical Engineers and Instrument Society of America. Contact G. S. Axelby, Westinghouse, Box 746, Baltimore 3, Md.

Nov. 4–6—Eastern Analytical Symposium and Instrument Exhibit, New York City (*New Yorker*), sponsored by four Eastern sections of Society for Applied Spectroscopy, among others.

Nov. 12–13—Second Annual Texas Conference on Utilization of Atomic Energy, College Station (*Texas A & M*). Contact George M. Krise, Radiation Biology div., Texas Engineering Experiment Station, College Station.

Nov. 15–20—Conference of Radiological Society of North America, Chicago (*Palmer House*). Contact RSNA, 815 Medical Arts Bldg., Ft. Worth, Tex.

Nov. 16–21—Conference on Disposal of Radioactive Wastes, Monaco, sponsored by International Atomic Energy Agency. Contact IAEA, 11–13 Karntner Ring, Vienna 1.

Nov. 19–20—Sixth Annual Meeting of the Professional Group on Nuclear Science of the IRE in conjunction with the New England Regional Electronics Meeting, Boston, Mass. (*Commonwealth Armory*). Contact Hugh Stoddart, Atomium Corp., 940 Main St., Waltham, Mass.

Nov. 20–21—Texas Symposium on Nuclear Fusion, sponsored by Univ. of Texas and Texas Atomic Energy Research Foundation, Austin. Contact Texas Symposium on Nuclear Fusion, P.O. Box 8005, University Station, Austin.

Nov. 26–29—International Conference on Legal and Administrative Problems of Peaceful Use of Nuclear Energy, Rio Piedras, Puerto Rico. Contact Prof. Jaro Mayda, University of Puerto Rico, Rio Piedras.

Dec. 7–9—Seminar on Nuclear Ship Propulsion (with special emphasis on safety) sponsored by the International Atomic Energy Agency, Vienna. Contact IAEA 11–13 Karntner Ring, Vienna 1, Austria.

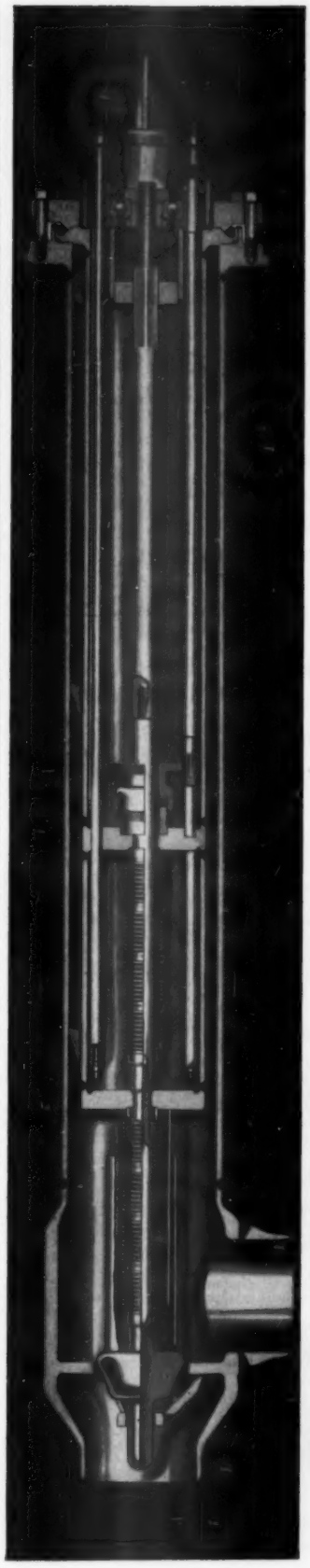
Feb. 10–11—Symposium on Gas-cooled Reactors, sponsored by Franklin Institute and Delaware Valley Section, American Nuclear Society, Philadelphia. To cover both U. S. and U. K. programs and include a British speaker at banquet Feb. 10. Contact Francis L. Jackson, FI, Philadelphia 3.

Feb. 14–18—Annual Meeting of American Institute of Mining, Metallurgical and Petroleum Engineers, New York. Contact AIMMPE, 29 W. 39th St., N. Y. 18, N. Y.

Feb. 25–26—7th Scintillation Counter Symposium, Washington, D. C. (*Shoreham*). Deadline for abstracts is Dec. 15. Contact G. T. Reynolds, Princeton Univ., Princeton, N. J.

April 3–8—6th Nuclear Congress, New York City (*Coliseum*). Includes 6th Nuclear Engineering & Science Conference, 8th Atomic Energy in Industry Conference and 6th International Atomic Exposition. Contact E. B. Gunyou, Curtiss-Wright Corp., Princeton, N. J.

May 9–13—Instrument Society of America, San Francisco. For papers on measurement and control instruments contact Martin E. Kantor, c/o General Atomic, P.O. Box 608, San Diego 12, Calif.



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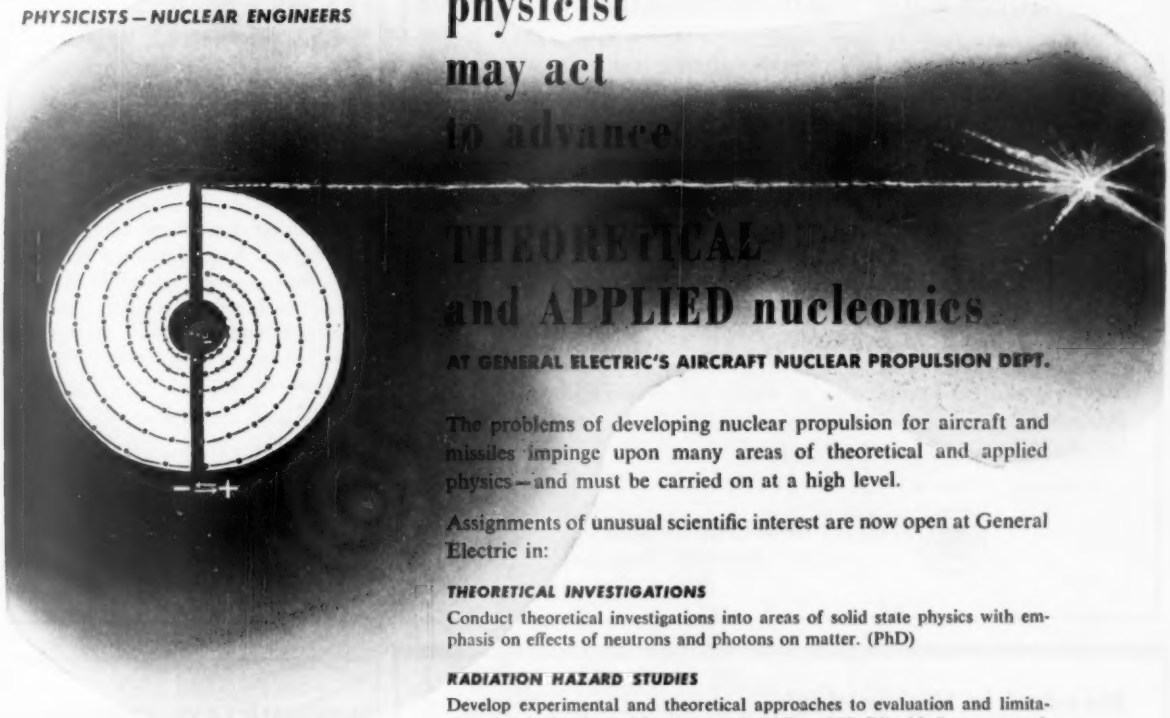

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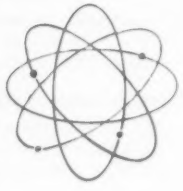

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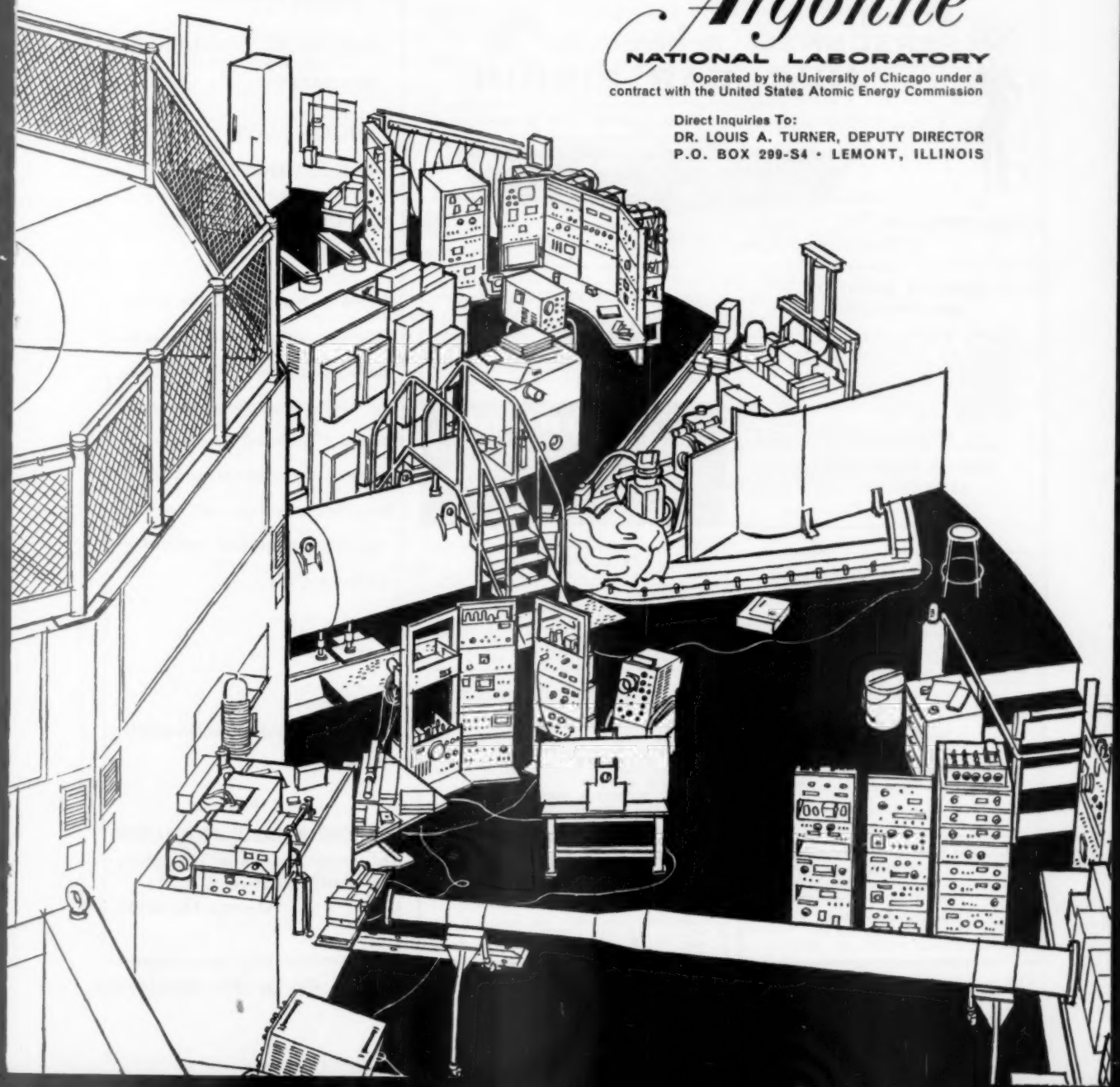

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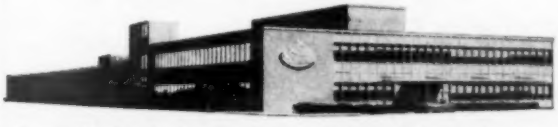

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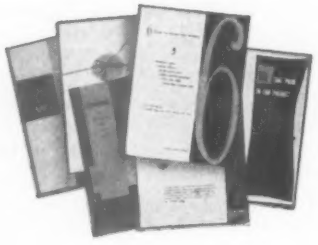

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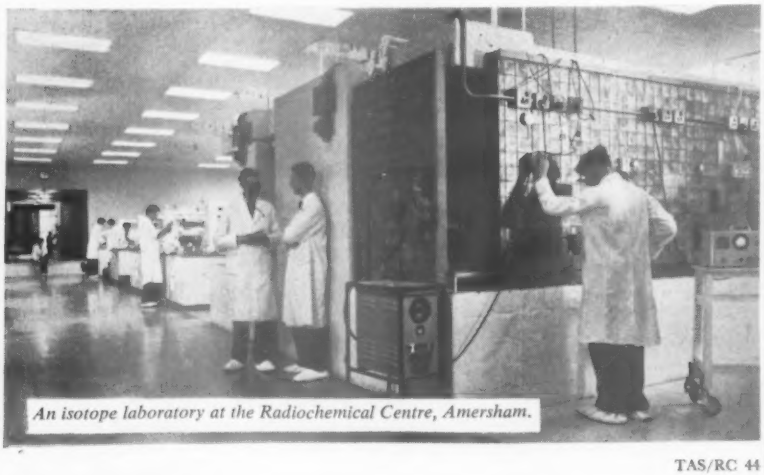

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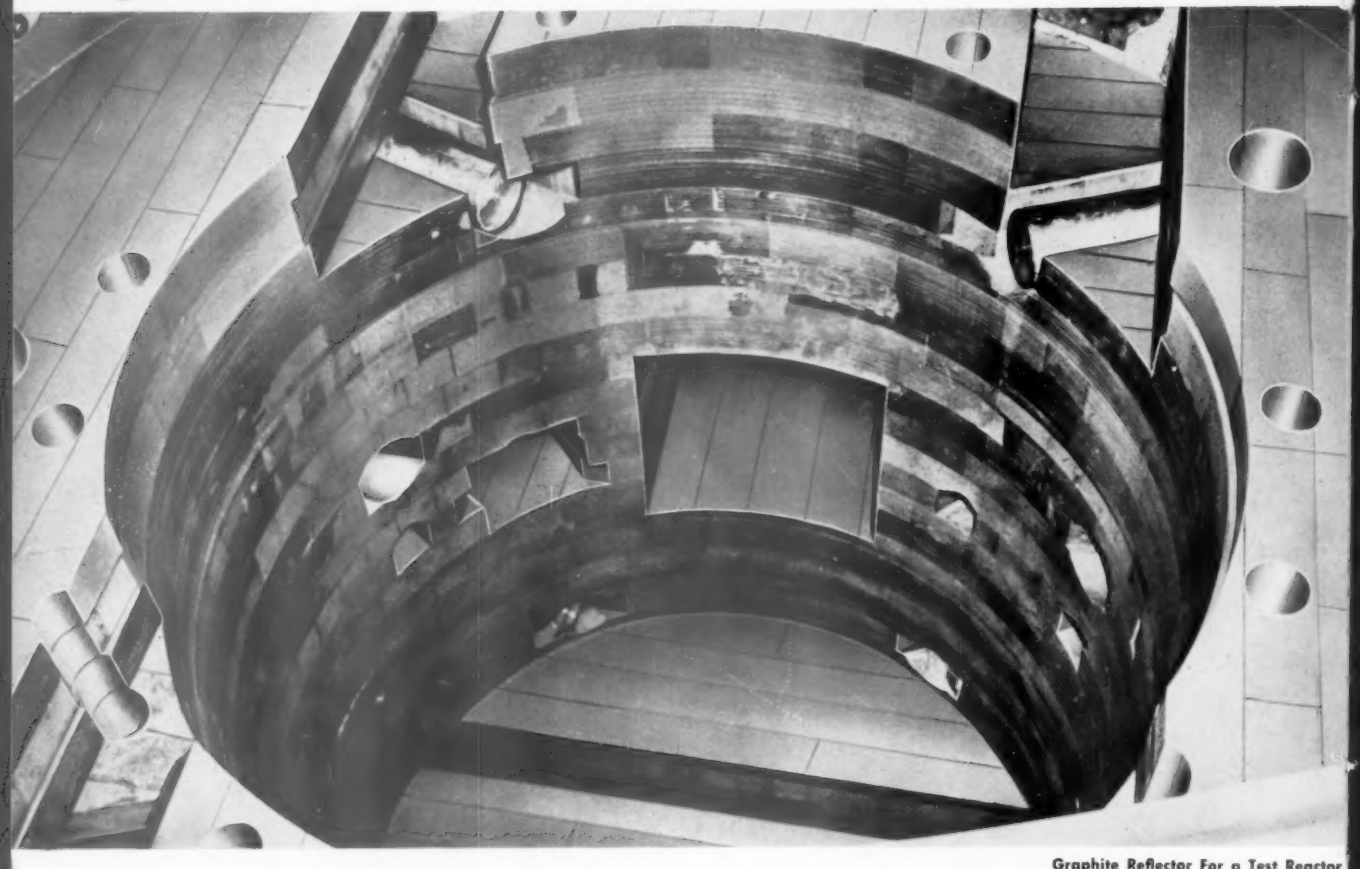

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Microscopic scattering cross section (barns)*	5.09	5.09
Macroscopic absorption cross section ($cm^{-1} \times 10^5$)	38.30	33.67
Macroscopic scattering cross section (cm^{-1})	0.432	0.432
Average logarithmic energy decrement per collision	0.158	0.158
SLOWING DOWN POWER	0.0684	0.0684
MODERATING RATIO	177.5	203
REFLECTING RATIO	1125	1285
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